NATURAL RESOURCES

Puget Sound Seagrass Monitoring Report

Monitoring Year 2016 - 2017

03/11/2019

PUGET SOUND ECOSYSTEM MONITORING PROGRAM

WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES
HILARY S. FRANZ | COMMISSIONER OF PUBLIC LANDS

DNR monitors abundance and depth distribution of native seagrasses to determine status and trends in greater Puget Sound through the Submerged Vegetation Monitoring Program (SVMP) (https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-eelgrass-monitoring).

The Submerged Vegetation Monitoring Program is a component of the Puget Sound Ecosystem Monitoring Program (PSEMP) (https://sites.google.com/a/psemp.org/psemp/home).

Cover Photo: Eelgrass at Dumas Bay, Federal Way. Photo credit: Lisa Ferrier.

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The following document fulfills DNR's Eelgrass Monitoring Performance measure. It also fulfills tasks in the Puget Sound Partnership's Action Agenda by providing information on the status and trends of one of the selected indicators of environmental health in Puget Sound.

The authors of this report are Bart Christiaen, Lisa Ferrier, Pete Dowty, Jeff Gaeckle and Helen Berry. Multiple people played a critical role in the video data collection and post-processing for the work summarized in this report including Cailan Murray, Olivia Mitchell, Jessica Olmstead, Lindsay Anderson, and Evan Sutton.

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http://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-publications

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Contents

Executive summary

The Washington State Department of Natural Resources (DNR) manages 2.6 million acres of State-Owned Aquatic Lands for the benefit of current and future citizens of Washington State. DNR's stewardship responsibilities include protection of native seagrasses, such as eelgrass (*Zostera marina*) and surfgrass (*Phyllospadix spp.*), important components of nearshore ecosystems in greater Puget Sound. DNR monitors abundance and depth distribution of native seagrasses to determine status and trends in greater Puget Sound through the Submerged Vegetation Monitoring Program (SVMP). Soundwide monitoring was initiated in 2000. The monitoring results are used by DNR for the management of State Owned Aquatic Lands, and by the Puget Sound Partnership as one of 25 Vital Signs to track progress in the restoration and recovery of Puget Sound.

Key findings:

Soundwide native seagrass area was relatively stable between 2000 and 2017

- The relative stability is reassuring and sets Puget Sound apart from many other developed areas, where substantial system-wide declines are ongoing.
- There is some evidence for a slight increase in soundwide seagrass area based on a new analysis that compares individual years sampled with the same panel of sites.
- At this point in time, it seems unlikely that the PSP goal of 20% increase in native seagrass area by 2020 will be met. Stressors that affect seagrass in Puget Sound will likely need to be reduced to see significant soundwide gains in seagrass area, depth distribution and overall health.
- The annual estimates of soundwide native seagrass area were 24,906 +/- 1914 ha in 2016 and 23,434 +/- 2119 ha in 2017 (Figure A). The 3-year soundwide average for 2015-2017 is 23,142 +/- 1115 ha. These values are below the PSP target of a 20% increase in native seagrass area by 2020.

Declines documented in vulnerable areas

- While the majority of sites appear stable or increasing, the spatial pattern in site level trends suggests that native seagrasses are more susceptible to declines in certain areas of greater Puget Sound.
- Declines are mostly centered in south Central Puget Sound and near the San Juan Islands (Figure B and Figure C). Seagrass seems particularly vulnerable at the end of inlets or in protected embayments.

Causal factors identified for increases and declines

- Between 2014 and 2017 there was a small but widespread decline in shallow portions of native seagrass beds throughout greater Puget Sound. Given the spatial scale of these declines, it is likely that they are related to the unusual environmental conditions observed in 2015 and 2016 throughout greater Puget Sound.

- We have documented several declines at locations with known or suspected water quality impairments. Locations of concern include the heads of Case and Carr Inlet, inner Quartermaster Harbor, and sites near a shallow outfall on Orcas Island.
- Other likely drivers for specific site-level declines include extreme weather events, eelgrass wasting disease, high abundance of green macro-algae, and changes in river flow patterns across deltaic flats in greater Puget Sound.

Spatial patterns

- Surfgrass is mostly found along the exposed rocky coasts of the San Juan Islands and the Strait.
- Eelgrass beds are widespread but have different characteristics depending on their location. Regional patterns are apparent in both the spatial and the depth distribution of eelgrass in greater Puget Sound.
  - The spatial distribution of eelgrass is in part determined by the amount of available habitat. The largest eelgrass beds are found on tidal flats in Padilla, Samish and Skagit Bay.
  - The depth range at which eelgrass grows differs depending on overall water clarity and tidal range. Eelgrass has a more restricted depth distribution in south Central Puget Sound and the Saratoga Whidbey Basin. There are also gradients in depth distribution near enclosed embayments such as Quartermaster Harbor, Kilisut Harbor and Port Orchard.
- *Zostera japonica* is detected at nearly 30% of all sites sampled by the SVMP. This non-native seagrass is widespread in all regions of greater Puget Sound, except the San Juan Islands and the Strait of Juan de Fuca.

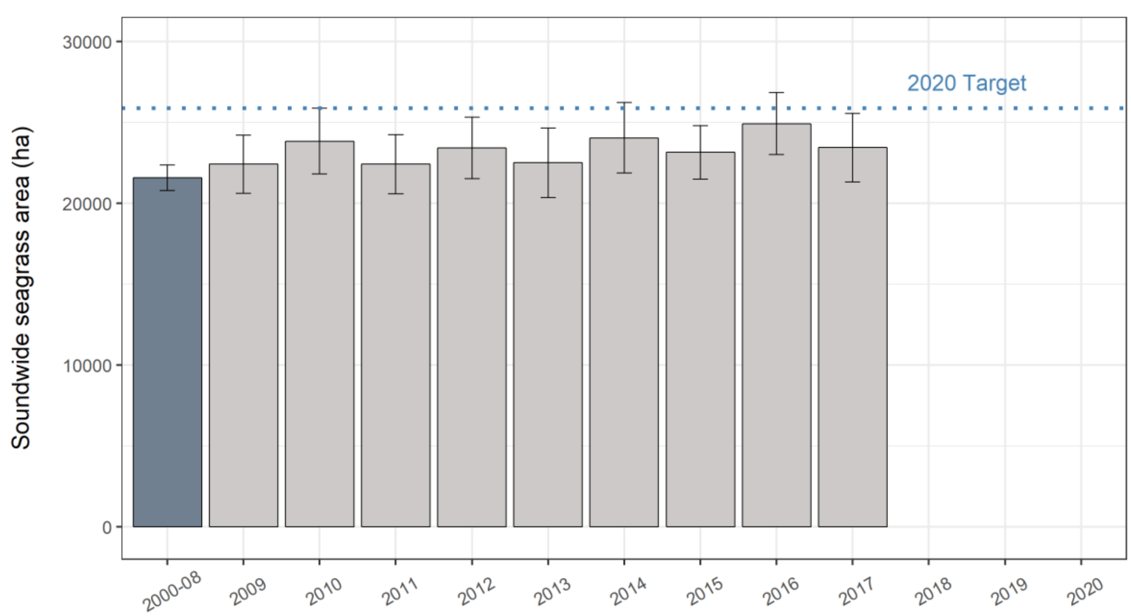

Figure A: Long-term trend in soundwide seagrass area in greater Puget Sound

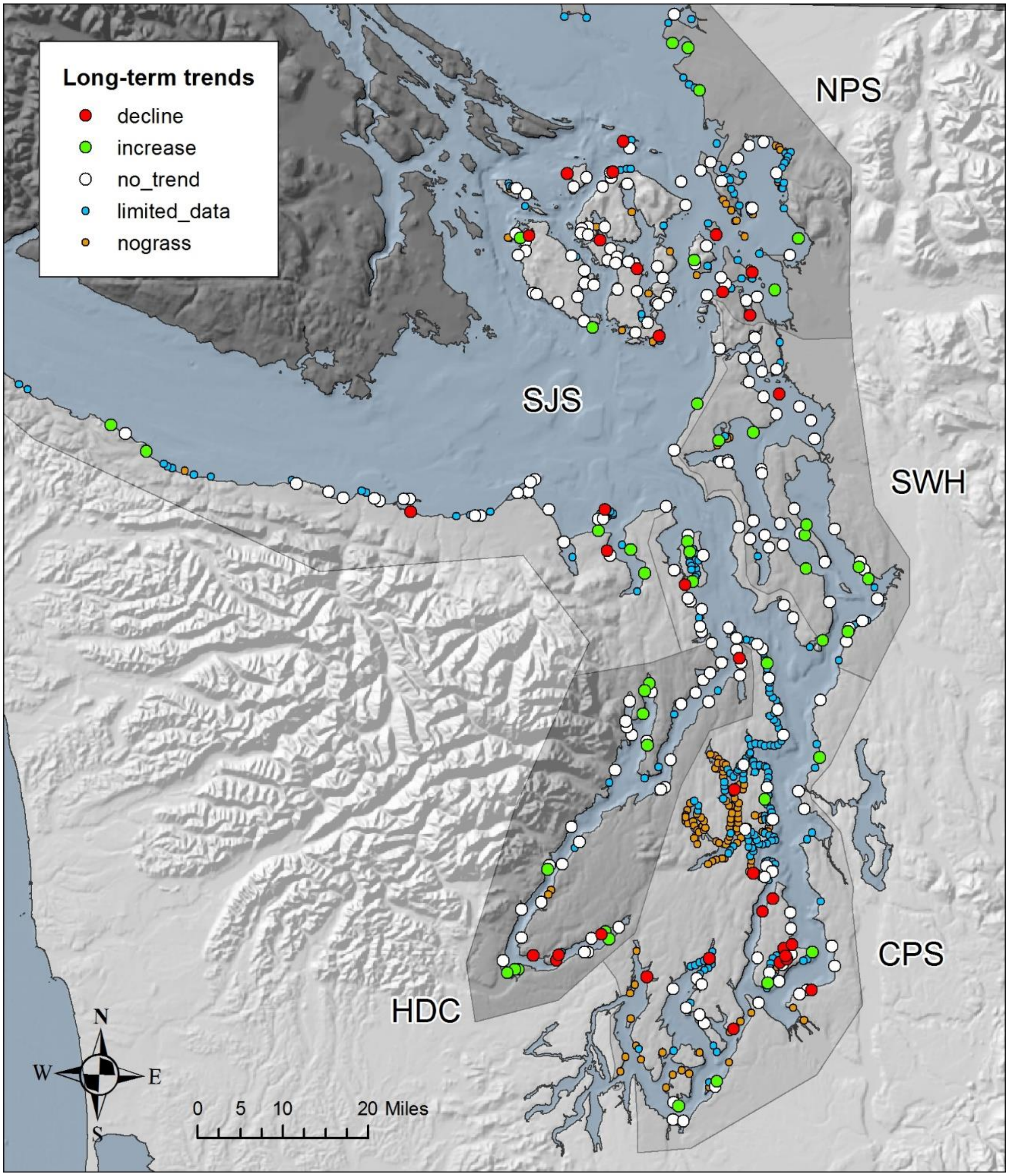

Figure B: Long-term trends in site seagrass area between 2000 and 2017

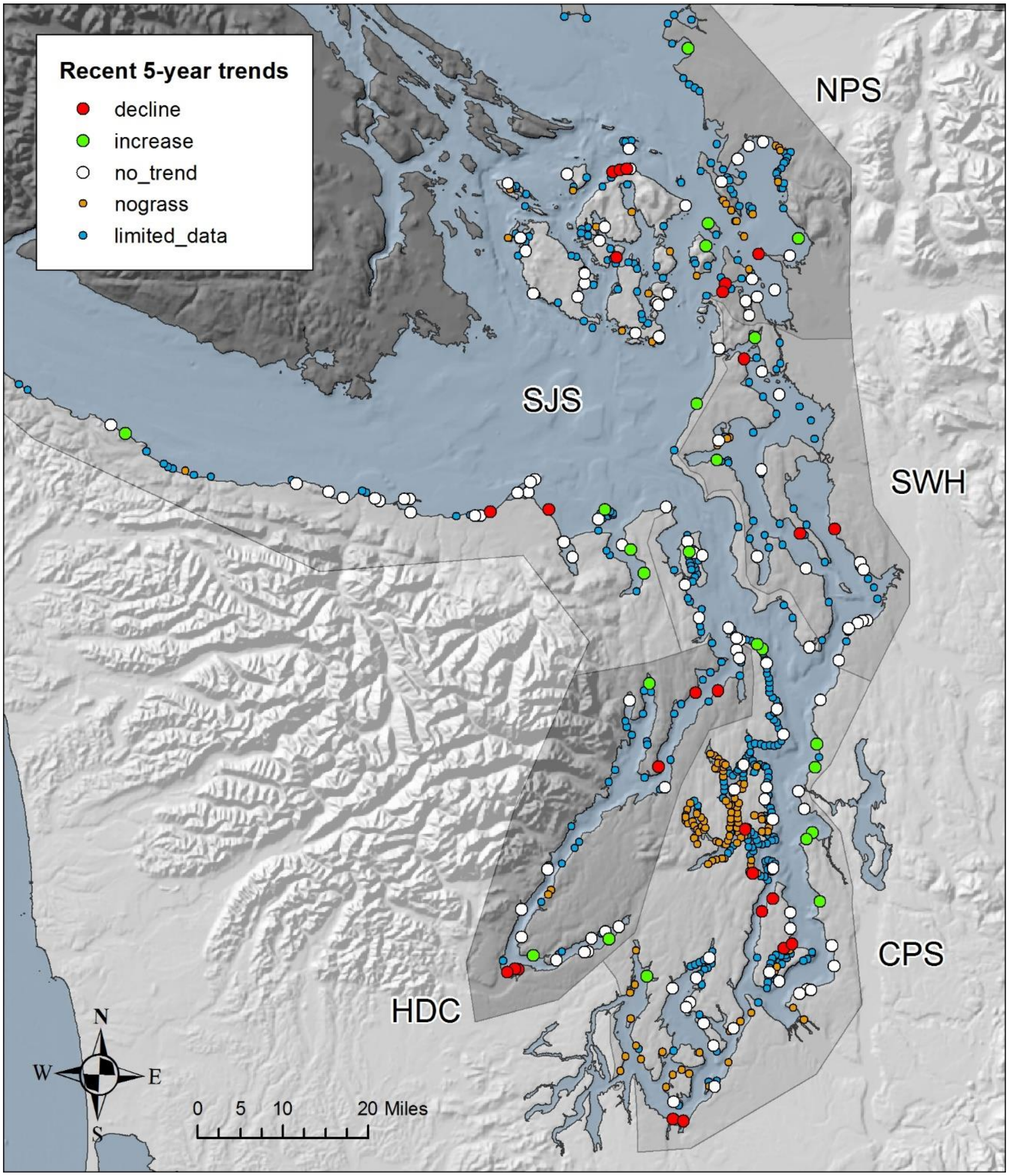

Figure C: Recent 5-year trends in site seagrass area (2013-2017)

1 Introduction

1.1 Seagrass ecosystems on a global scale

Seagrasses are flowering plants that grow submerged in marine environments. These plants flower, fertilize and set seeds underwater, but often spread through vegetative growth (Cox 1998, Kendrick et al. 2012). There are approximately 60 species worldwide, which belong to 5 plant families[1] (Den Hartog and Kuo 2006, Green and Short 2003). Despite their limited diversity, seagrass beds play an important role in the food-webs of coastal ecosystems throughout the world. They are ranked among the most productive and valuable habitats in the biosphere (Costanza et al. 1997), and provide food and shelter for a wide variety of animal species, including benthic invertebrates, commercially important fish species, wading birds, turtles, dugongs and manatees (Orth et al. 1984, Gillanders 2006, Bertelli & Unsworth 2014). Seagrasses are able to reduce erosion and improve water quality by stabilizing sediments with their roots and rhizomes (de Boer 2007). They are an important sink for carbon on a global scale (Fourqurean et al 2012), and have the potential to mitigate some effects of ocean acidification (Unsworth at al. 2012, Manzello et al. 2012, Hendriks 2014). Recent studies also suggest that seagrass beds are able to reduce the relative abundance of potentially pathogenic bacteria from the water column (Lamb et al. 2017), and that algicidal bacteria associated with seagrass leaves may influence the abundance of harmful algae in nearshore environments (Inaba et al. 2017).

Globally, seagrass ecosystems are in decline (Waycott et al. 2009). These declines are often attributed to the increased human development in coastal watersheds. Seagrasses are vulnerable to eutrophication, caused by the excessive input of nutrients and organic matter in coastal marine ecosystems (Rothausler et al. 2016, Krause-Jensen et al. 2008). Under these circumstances, they can be light-limited by high biomass of phytoplankton, macroalgae and epiphytes (Burkholder et al. 2007). High amounts of organic matter can also lead to increased sulfide concentrations in sediment pore-waters, which negatively impact seagrass photosynthesis, metabolism and growth, especially at low dissolved oxygen concentrations in the water column (Holmer et al. 2005, Plus et al. 2003, Holmer et al. 2001). Other human activities, such as land conversion, construction projects, dredge and fill operations, trawling, and recreational boating can either physically damage seagrass beds, or increase turbidity and negatively impact seagrass beds through shading and siltation (Hemminga and Duarte, 2000).

[1] 5 families if you classify the *Ruppia maritima* as a seagrass (for the purpose of this report, we consider *R. maritima* a seagrass)

Because of their wide geographic distribution and sensitivity to human disturbances, seagrass beds are often used to determine the health of coastal ecosystems (Marba et al. 2013). Monitoring programs use a variety of indicators to assess the status of seagrass beds, such as meadow distribution and extent, maximum depth limits, shoot density, biomass, leaf morphology, and the chemical composition of the plants (Roca et al. 2016).

1.2 Seagrass in greater Puget Sound

There are 6 seagrass species in Washington State: *Zostera marina*, *Zostera japonica*, *Phyllospadix serrulatus*, *Phyllospadix scouleri*, *Phyllospadix torreyi* and *Ruppia maritima*. *Zostera marina* (eelgrass) is by far the most abundant seagrass species in greater Puget Sound. Eelgrass provides similar ecosystem services as other seagrass species. In particular, it offers spawning grounds for Pacific herring (*Clupea harengus pallasi*), out-migrating corridors for juvenile salmon (*Oncorhynchus* spp.) (Phillips 1984, Simenstad 1994), and important feeding and foraging habitats for waterbirds such as the black brant (*Branta bernicla*) (Wilson and Atkinson 1995) and great blue heron (*Ardea herodias*) (Butler 1995). In addition, eelgrass beds are valued hunting grounds and ceremonial foods for Native Americans and First Nation People in the Pacific Northwest (Suttles 1951, Felger and Moser 1973, Kuhnlein and Turner 1991, Wyllie-Echeverria and Ackerman 2003). As with other seagrass species, eelgrass responds quickly to anthropogenic stressors. Because of this, eelgrass has been selected as one of 25 Vital Signs used by the Puget Sound Partnership to track progress in the restoration and recovery of Puget Sound (PSP 2019).

Other Washington State agencies also recognize the value of seagrass beds as an aquatic resource. The Washington State Department of Fish and Wildlife designated eelgrass beds as habitats of special concern (WAC 220-110-250) under its statutory authority over construction projects in state waters (RCW 77.55.021). Similarly, the Washington State Department of Ecology designated eelgrass areas as critical habitat (WAC 173-26-221) under its statutory authority to implement the state's Shoreline Management Act (RCW 90.58).

1.3 Monitoring seagrass in greater Puget Sound

The Washington State Department of Natural Resources (DNR) is steward of 2.6 million acres of state-owned aquatic lands. As part of its stewardship responsibilities, DNR monitors the native seagrass population (*Zostera marina* and *Phyllospadix spp.*) across the nearshore of greater Puget Sound. Observations of the non-native seagrass *Zostera japonica* are also recorded as part of monitoring but these are excluded from SVMP area estimates because this species has a number of distinct resource management issues (Shafer et al. 2014).

DNR's seagrass monitoring is conducted on an annual basis by the Submerged Vegetation Monitoring Program (SVMP) – a component of the Nearshore Habitat Program in DNR's Aquatic Resources Division. The SVMP is one component of the broader Puget Sound

Ecosystem Monitoring Program (PSEMP), a multi-agency monitoring program coordinated by the Puget Sound Partnership (PSP).

SVMP data is used to determine the status of the PSP's eelgrass Vital Sign (PSP 2019). Earlier ecosystem indicator efforts in Puget Sound also included results from the SVMP (PSP 2017, 2015, 2013). In February 2011, the Partnership adopted a restoration target for eelgrass that reflects a 20% gain in soundwide area by 2020 (PSP 2011). In order to identify approaches to reach the target, the Partnership and DNR facilitated development of a multi-agency strategy for protection and restoration of eelgrass in 2014 (Goehring et al. 2015).

This report summarizes the methods and key results from the latest SVMP analysis. This analysis is based on the most recent version of the monitoring dataset that spans 18 years (2000-2017) and includes data from 2,704 site samples, 33,417 video surveys, and 11,841,082 points where seagrass has been classified.

1.4 Data access

The SVMP monitoring database and a User Manual are available through the DNR GIS data download web page. The User Manual (Dowty et al. 2019) includes a more detailed description of project methods than are included in this report. The data is also accessible through an online data viewer. These resources are available at the following webpages:

https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-eelgrass-monitoring

https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/puget-sound-eelgrass-monitoring-data-viewer

http://data-wadnr.opendata.arcgis.com

2 Methods

A comprehensive presentation of SVMP methods is available in the User Manual distributed with the digital dataset (Dowty et al. 2019). Here, a brief overview of methods is presented and recent developments are highlighted.

2.1 Overview of SVMP methods

The SVMP is a regional monitoring program, initiated in 2000, designed to provide information on both the status and trends of native seagrass species (*Zostera marina* and *Phyllospadix spp*.) in greater Puget Sound. This program uses towed underwater video to generate estimates of area and depth distribution for subtidal seagrass beds in places where airborne remote sensing cannot detect the deep edge of the bed. Observations of the non-native seagrass *Zostera japonica* are also recorded as part of monitoring but these are excluded from estimates of area and depth distribution. Because *Z. japonica* is excluded, we refer to native seagrass area as seagrass area throughout the report.

2.1.1 Equipment

Field sampling is generally conducted from May to August. DNR contracts an 11 m research vessel, the *R/V* Brendan D II. This vessel is equipped with an underwater video camera mounted in a downward-looking orientation on a weighted towfish. Parallel lasers mounted 10 cm apart create two red dots in the video images for scaling reference. The towfish is deployed directly off the stern of the vessel using an A-frame cargo boom and hydraulic winch. The weight of the towfish positions the camera directly beneath a DGPS antenna, ensuring that the data accurately reflects the geographic location of the camera. Time, differential global positioning system (DGPS) data, Garmin and BioSonics echo sounder data are acquired simultaneously during sampling. Differential corrections are received from the United States Coast Guard public DGPS network using the WSG 84 datum. Table 1 lists the equipment used to conduct video sampling and acquire seagrass depth data.

2.1.2 Study area, sample frames, and stratification

The SVMP is limited to greater Puget Sound, also known as the U.S. portion of the Salish Sea. The extreme reaches of southern Puget Sound are excluded from the annual monitoring study because native seagrass species rarely occurs in this area (Berry et al. 2003). The study area is further divided into 5 basins: Northern Puget Sound (NPS), Central Puget Sound

(CPS), Hood Canal (HDC), the Saratoga-Whidbey Basin (SWH) and the San Juan Islands and the Strait of Juan de Fuca (SJS). All of the potential seagrass habitat in greater Puget Sound was divided into 2,467 sample sites. These sites belong to one of two sample frames: flats (n = 74) or fringe sites (n = 2393). The flats category includes embayments, tide flats and river deltas, potential habitat that is best represented as areal sample units. The fringe category contains potential habitat along a narrow band parallel to the shoreline, and is well represented by linear sample units.

Sites are bound by the -6.1 m MLLW bathymetry contour and the ordinary high water mark as described in the SVMP methods (Berry et al. 2003, Figure 3). Fringe sites are 1000 m along the -6.1 m contour, while the segment lengths vary for flats sites (e.g., depending on embayment size).

Each sample frame is further divided into 3 strata: the flats frame is divided into core (n = 4), persistent flats (n = 3), and rotational flats (n = 67), while the fringe frame is divided into core (n = 2), narrow fringe (n = 1,965) and wide fringe (n = 426). These strata form the basis for the statistical framework used to estimate soundwide seagrass area.

2.1.3 Sample polygons and transect selection

At each site, we randomly select a number of transects that are oriented perpendicular to shore and span the entire width of the sample polygon. These transects are surveyed using towed underwater videography to determine the presence/absence of seagrass using a modified line-intercept technique (Norris et al. 1997). Sample polygons are determined prior to sampling.

- Before 2016, we delineated sample polygons which encompassed all eelgrass and surfgrass but did not necessarily span the entire length of a site. We drew a new Simple Random Sample (SRS) of transects each time we sampled a site.
- Starting in 2016, methods for transect selection and sample polygon delineation were changed. We repeat previously measured transects (SRS) and in addition measure seagrass along transects selected by Stratified Random Sampling (STR) along the entire length of the site regardless of the seagrass distribution.

2.1.4 Data processing

Video is reviewed and each transect segment of nominal one-meter length (and one-meter width) is classified with respect to the presence of native (*Z. marina, Phyllospadix spp*.) and non-native seagrass species (*Z. japonica)*. All presence and absence classification results are recorded with corresponding spatial information, and stored in an ArcGIS geodatabase. The fractional cover of eelgrass and surfgrass along transects is used to calculate site seagrass area. Depth information collected along each transect is used to estimate mean maximum and minimum depth of seagrass at each site. All measured depths are corrected to the MLLW datum by adding the transducer offset, subtracting the predicted tidal height for the site and adding the tide prediction error (calculated using measured tide data from the National Oceanic and Atmospheric Administration website http://co-ops.nos.noaa.gov/data_res.html). Corrected depth data are integrated with survey data information, so each video frame has an associated date/time, GPS position and depth measurements corrected to MLLW datum.

Table 1: Current equipment and software used to collect underwater video, depth and positional data

Equipment	Manufacturer/Model
Differential GPS	Trimble AgGPS 132 (sub-meter accuracy)
Depth Sounders	BioSonics MX, Garmin FishFinder 250
Underwater Cameras	SplashCam Deep Blue Pro Color (Ocean Systems, Inc.)
Lasers	Deep Sea Power & Light
Underwater Light	Deep Sea Power & Light RiteLite (500 watt)
Navigation Software	Hypack Max
Video Overlay Controller	Intuitive Circuits TimeFrame
DVD Recorder	Sony RDR-GX7
Digital Video Recorders	DataVideo DN-700 / DV recorder, Atomos Ninja DV recorder

2.1.5 Studies and site selection

The SVMP encompasses several sample efforts[2], which are referred to as studies in this report:

- The backbone of the program is called the soundwide study. This study generates regional estimates of seagrass area in greater Puget Sound from a subset of sites which are selected using a statistical framework (n = 78 - 80 sites). The core and persistent flats strata are completely surveyed each year. For the other strata (rotational flats, wide fringe and narrow fringe), a random sample of sites is visited. Until 2014, sites were sampled using a rotational sample design where 20% of sites were replaced by randomly selected sites each year. Sites remained in the sample pool for 5 years before rotating out (Dowty et al. 2019). From 2015 onwards, sites are selected using a 3-year rotating panel design (Figure 1), where 3 alternating panels of independent sites are resampled every 3 years. For more information on the rotating panel design, see section 2.2.
- The focus area study ran from 2004 to 2012. Each year, we sampled a number of additional randomly selected sites in one of five sub-regions (CPS, HDC, NPS, SWH and SJS-CYP) to produce estimates at the sub-region (or focus area) scale with a return every five years to the same focus area.
- In 2013 and 2014, new site survey methods were tested at a subset of sites to evaluate techniques to improve the precision of site results. In addition to special studies implemented by the Program, the SVMP frequently completes surveys to characterize the status of local seagrass beds in collaboration with other research, resource management, and citizen groups. Results from these site surveys are outside the regional design and do not contribute to estimates of soundwide seagrass area, but do provide a greater understanding of seagrass distribution throughout Puget Sound and form a baseline for assessing change in future surveys.

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[2] The Friends of the San Juan Islands and Island County MRC have collected data using similar methods as the SVMP. These data are not included in this report, but are available through the SVMP database.

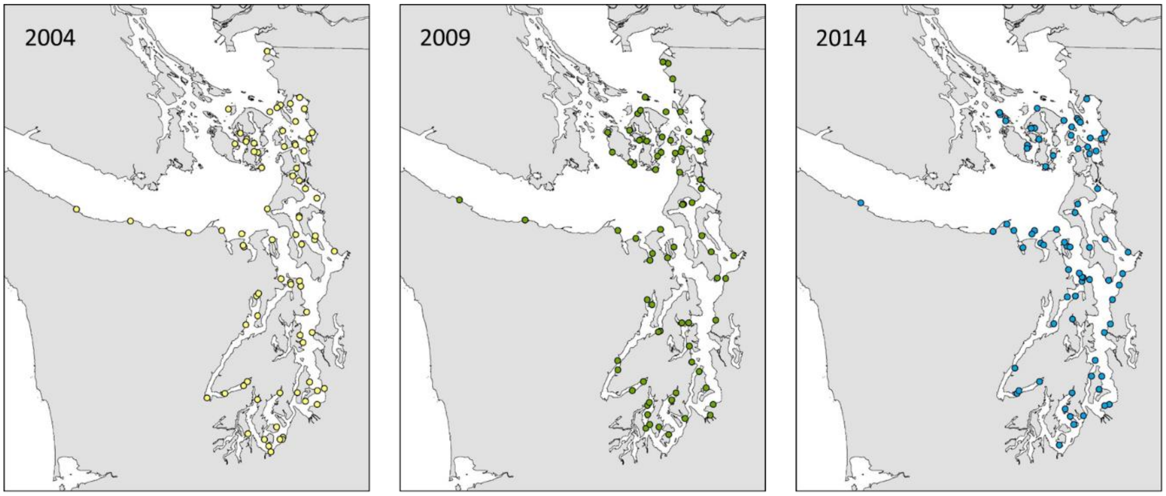
2.2 Rotating panel design

Regional monitoring programs, such as the SVMP, are often unable to census (completely measure) the ecosystem of interest. Instead, a representative sample of sites is visited, and results from this sample are extrapolated to the regional scale. Such monitoring programs can be optimized to provide a good mean status estimate of an ecosystem (sample as many sites as possible, for example by taking a new random draw of sites every year the monitoring is conducted, 100% rotation), or to provide a good estimate of trend (resample the same sites over time, 0% rotation). Each of these designs have weaknesses and strengths. Sample designs with 100% rotation are able to provide a good picture of the distribution of habitat characteristics over large spatial scales, but regional trend estimates have low precision, and there is no ability to generate trend estimates for individual sites. Regional trend estimates based on sample designs without rotation have high precision, but may not be accurate if the number of sites sampled is relatively low compared to the number of potential sample sites in the region. If the sample size is too low, a regional trend detected based on this design may not be representative of the region as a whole.

In order to satisfy the competing goals of estimating status and trends of seagrass populations in greater Puget Sound, the SVMP previously employed a design with 20% rotation: sites were randomly selected (within a stratum) and followed for a period of 5 years, after which they were replaced by new randomly selected sites. Because of this, the SVMP was able to sample over 400 different sites throughout greater Puget Sound between 2000 and 2014. In addition, this design made it possible to estimate trends over time on both a site-level and a soundwide spatial scale. However, the 20% rotation in site selection introduced a number of problems for estimating trends in soundwide seagrass area (Dowty 2018). Site rotation had an effect on trend estimates because the 5-year retention of sites made the trend estimates highly variable as compared to designs with zero or 100 percent rotation.

In 2015, the SVMP switched to a new 3-panel design. This new design improves our capability to detect trends in soundwide seagrass area, at the cost of limiting the number of new sites introduced over time. We revisit all sites sampled in either 2004, 2009 or 2014 on a 3-year basis; and use 3-year averages of these samples to generate unbiased estimates of soundwide seagrass area in greater Puget Sound (Figure 1). The new 3-panel design covers 214 unique sites. Some of these sites belong to more than one panel, but the majority of sites are sampled once every 3 years. In addition to the standard panels, we also measure a number of sites of interest. These additional sites are not part of the random sample, and are not used to generate an estimate of soundwide seagrass area. However, they do allow us to expand the footprint of the monitoring to new parts of Puget Sound, or focus on site level trends in areas of concern.

The new design affects our ability to detect trends at smaller spatial scales. In the past, most sites were visited annually for 5-year stretches of time. This allowed us to look at inter-annual variability in seagrass beds at the site level, but limited us in our ability to detect long-term trends. Now we will visit each site in the new panel design indefinitely on a 3-year basis. This limits our ability to detect change on short timeframes, but does allow for better detection of long-term trends. We can improve our ability to detect short term change by altering our sampling protocols at the site level.



Sample schedule – SVMP redesign																				REPORT OUT
00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	2020

Figure 1: Modified site selection: 3-year rotating panel design. In 2015 and 2018, we resample sites from the 2004 panel. In 2016 and 2019, we resample sites from 2009, and in 2017 and 2020, we resample sites from 2014.

2.3 Repeat transects – sample selection

2.3.1 Repeat transects

In the original SVMP design, sites were assessed by delineating a sample polygon (which encompasses the entire area where eelgrass and surfgrass grows at a site), and sampling a random draw of transects that are located within the sample polygon and are oriented perpendicular to shore. Each time a site was visited we selected a new draw of transects using simple random sampling (SRS). Simple random sampling can produce clumping in the distribution of transects, and this can lead to samples that poorly represent the distribution of seagrass at a site. When the difference in area is estimated from a new draw of transects on two different occasions, the variance of the difference estimate not only reflects temporal variability, but also includes a component due to spatial variability in transect selection. Because of this, our site level trends had relatively low power, especially at sites with an uneven distribution of seagrass across the site (Dowty 2017). After transferring to the new rotating panel design, our ability to detect trends at the site level would become even worse if all other factors remained the same, since we now revisit sites only on a 3-year basis.

In order to mitigate for this effect, we switched in 2016 from sampling with new random draw transects to repeat surveys of previously selected transects. Paired analysis of repeat transects effectively controls for spatial variability and eliminates this component of the variance in the difference estimate. This can lead to large gains in precision, which vastly improves our ability to detect trends at the site level (Dowty 2017). To fully utilize the increased power of the sample design, new analysis methods are needed. Simply comparing seagrass area over time is not the most effective technique to analyze paired transect data.

2.3.2 Sample selection

As previously stated, simple random sampling can produce clumped samples that may not be representative when the distribution of seagrass is highly uneven at a site. Other sampling selection techniques, such as systematic sampling, or stratified sampling, may perform better at heterogeneously distributed seagrass beds (Figure 2).

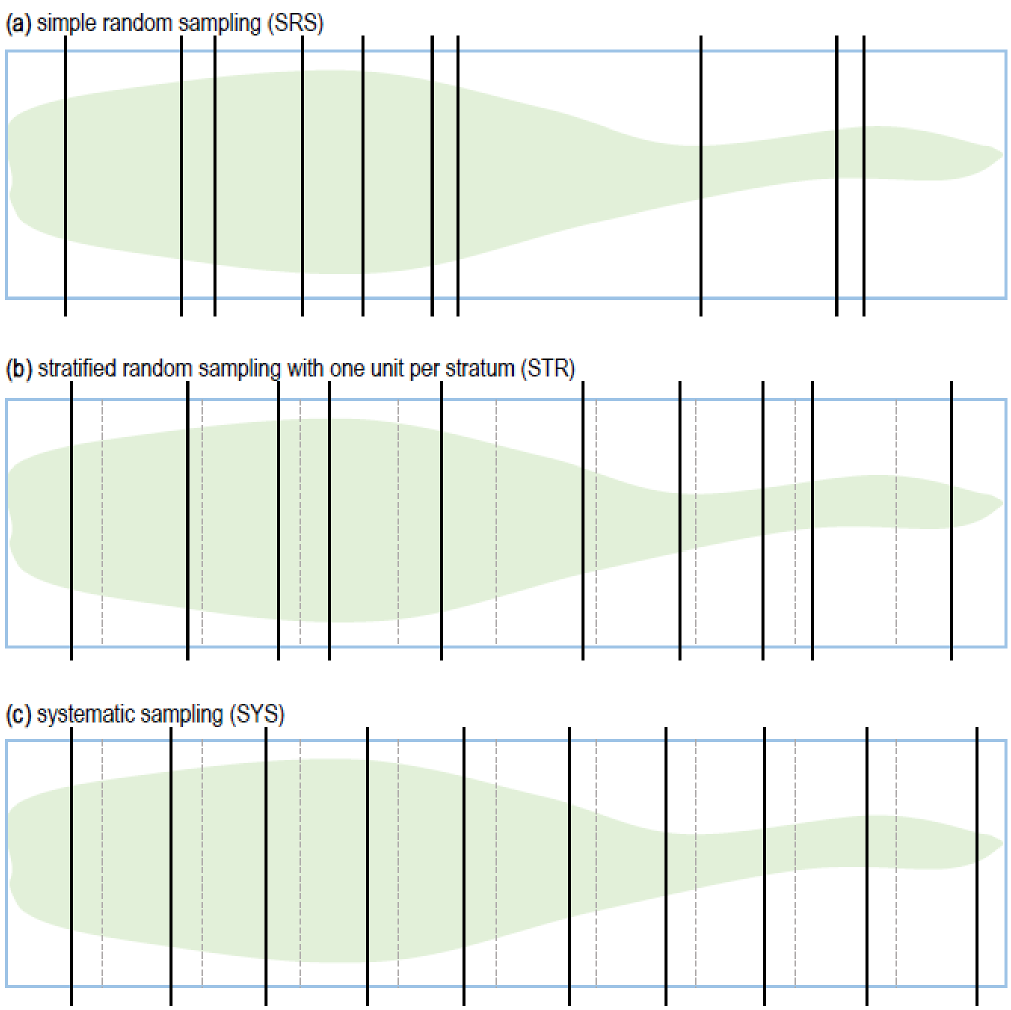


Figure 2: Different transect selection methods at the site level: (a) Simple random sampling, (b) stratified random sampling with one unit per stratum, and (c) systematic sampling (Source: Dowty 2017).

In 2016, we started sampling sites for the SVMP soundwide study with both transects selected by SRS and STR. In practice, this means that we repeat transects from the corresponding panel year (2004, 2009, and 2014), and supplement these with additional transects based on a stratified design. By sampling using SRS we maintain backwards compatibility in the dataset. By supplementing the SRS transects with STR, we have a better ability to detect new seagrass patches at sites where sample polygons previously did not span the entire length of the site. Sampling with STR also allows for more flexibility when using the data for other purposes, such as estimating understory kelp. The SVMP will need to develop a reliable approach to variance estimation to take full advantage of the potential of the STR design (Dowty 2017).

2.4 Analysis

Data was analyzed with ArcGIS and R (R Core Team 2018). We used several R-packages, including "broom" (Robinson and Hayes 2018), "dplyr" (Wickam et al. 2018), "ggplot2" (Wickam 2016), "tidyr" (Wickam and Henry 2018), and "weights" (Pasek et al. 2018).

2.4.1 Site area estimates

First, we estimate the percentage seagrass cover within the site-sample polygon $\hat{\hat{p}}$ using a ratio estimator of the form (1), where l_i is the vegetated length of transect i, and L_i is the total length of transect i at a site with m transects. The ratio has an approximate variance of (2), with $\bar{L}$ the average length of transects the site (Cochran 1977).

$$\hat{\hat{p}} = \frac{\sum_{i=1}^{m} l_i}{\sum_{i=1}^{m} L_i} \qquad (1)$$

$$Var_{\hat{\hat{p}}} = \frac{\sum_{i=1}^{m} \left(l_i - \hat{\hat{p}} L_i\right)^2}{(m-1)\, m\, \bar{L}^2} \qquad (2)$$

We estimate site seagrass area $\hat{X}$ by multiplying the percentage cover with the size of the sample polygon E (3). We then estimate the associated variance as (4).

$$\hat{X} = E\, \hat{\hat{p}} \qquad (3)$$

$$Var_{\hat{X}} = E^2 Var_{\hat{\hat{p}}} \qquad (4)$$

2.4.2 Soundwide seagrass area estimate

The estimator for seagrass area within a stratum takes one of three forms depending on whether it is a fringe stratum subject to probabilistic sampling (with linear extrapolation), a flats stratum subject to probabilistic sampling (with areal extrapolation) or a stratum that is subject to complete census (no extrapolation). For a stratum with *N* sites that is subject to complete census, seagrass area within the stratum (*B*) is estimated by (7) with the associated variance estimator (8), where $\hat{X}_i$ is the estimated average seagrass area at the i[th] site in the stratum.

$$\hat{B} = \sum_{i=1}^{N} \hat{X}_i \quad (7)$$

$$Var_{\hat{B}} = \sum_{i=1}^{N} Var_{\hat{X}_i} \quad (8)$$

For a fringe stratum with *N* sites, where each site is represented by a 1000 m line segment on the -6.1 m isobath, the estimator for seagrass area in the stratum is given by (9): n is the number of sites actually surveyed in the stratum, L_N is the total linear length of sample units in the stratum (i.e., the sampled population,) and L_T is the total length of the target population which includes orphan segments that are shorter than 1000 m but otherwise meet the criteria for inclusion in the stratum. The estimator for the associated variance is (10).

$$\hat{B} = \left(\frac{L_T}{L_N}\right) \left[\frac{N}{n} \sum_{i=1}^{n} \hat{X}_i\right] \quad (9)$$

$$Var_{\hat{B}} = \left(\frac{L_T}{L_N}\right)^2 \left[N^2 \frac{\left(1-\frac{n}{N}\right)}{n} s^2{}_{\hat{X}_i} + \frac{N}{n} \sum_i^n Var_{\hat{X}_i}\right],$$

where $s^2{}_{\hat{X}_i} = \frac{\sum_{i=1}^{n}\left(\hat{X}_i - \bar{\hat{X}}\right)^2}{(n-1)}$ and $\bar{\hat{X}} = \frac{\sum_{i=1}^{n} \hat{X}_i}{n}$ (10)

For the rotational flats stratum, we estimate seagrass area with a ratio estimator (Cochran 1977) of the form (11), where a_i is the area of the *i*th flats site and $A = \sum_{i=1}^{n} a_i$ is the total flats area within the stratum. The estimator for the variance of this estimate was derived by Skalski (2003) and is given by (12).

$$\hat{B} = A \left[\frac{\sum_{i=1}^{n} \hat{X}_i}{\sum_{i=1}^{n} a_i}\right] \quad (11)$$

$$Var_{\hat{B}} = N^2 \left(1 - \frac{n}{N}\right) \frac{\sum_{i=1}^{n}(X_i - a_i \hat{R})^2}{n\,(n-1)} + \frac{N \sum_{i=1}^{n} Var_{\hat{X}_i}}{n},$$

where $\hat{R} = \frac{\sum_{i=1}^{n} \hat{X}_i}{\sum_{i=1}^{n} a_i}$ (12)

2.4.3 Change in soundwide seagrass area 04-15, 09-16, 14-17

To estimate change in soundwide seagrass area between two years represented by the same sample of sites, we first calculate change in seagrass area for each individual site by subtracting the year1 estimate from the year2 estimate. We propagate the uncertainty around the change estimate by (13), where $Var_{\widehat{Diff_i}}$ is the estimated variance for the difference between area estimates in both years at site i.

$$Var_{\widehat{Diff_i}} = \sqrt[2]{Var_{\widehat{year2_i}} + Var_{\widehat{year1_i}}} \qquad (13)$$

We then use the change in seagrass area and uncertainty around the change estimate as input for an extrapolation per stratum, similar to the soundwide seagrass area estimate in section 2.4.2.

2.4.4 Multiyear estimates of soundwide seagrass area

Our annual estimates of soundwide seagrass area are based on a sample of 78 to 80 sites (depending on the panel). It is possible to increase the sample size for this calculation by combining sites from multiple panels. By combining data from 3 panels the sample size increases from ~78-80 to 214. Calculations are similar to the soundwide seagrass area estimate as described in section 2.4.2.

Several sites (mainly core and persistent flats) are sampled each year. For these sites we calculate the mean seagrass area and pooled variance by (14) and (15), where X_i = mean seagrass area at a site for year i; k = the number of years a site is sampled, n_i = the sample size for year I, and Var_i is the sample variance the site for year i.

$$\overline{X} = \frac{\sum_{i=1}^{k} Xi}{k} \qquad (14)$$

$$Pooled\ Var = \frac{\sum_{i=1}^{k} (n_i - 1)\ Vari}{\sum_{i=1}^{k} (n_i - 1)} \qquad (15)$$

2.4.5 Repeat transect analysis

In order to assess trends in seagrass cover over time for individual sites, we estimate the change in the presence/absence of eelgrass and surfgrass along individual transects using paired T-tests. These tests evaluate the statistical significance of mean change based on the change in fraction vegetated along each transect, weighted by transect length.

3 Results

3.1 Overview of the SVMP from 2000 to 2017

3.1.1 SVMP sample effort

Every year since 2000, we have sampled approximately 80 randomly selected sites to produce a regional estimate of native seagrass area in greater Puget Sound. In 2004, we started sampling additional sites as part of several projects. As a result our annual sample effort has increased over time, from 65 sites visited in 2000 to 141 sites visited in 2017 (Figure 3). The years 2014 and 2016 had the largest sample effort in terms of total sites visited. This is in large part due to the additional funds available as part of two interagency agreements with the Suquamish Tribe and the City of Bainbridge Island. Overall, we have collected 2704 site samples during 2191 site visits between 2000 and 2017.

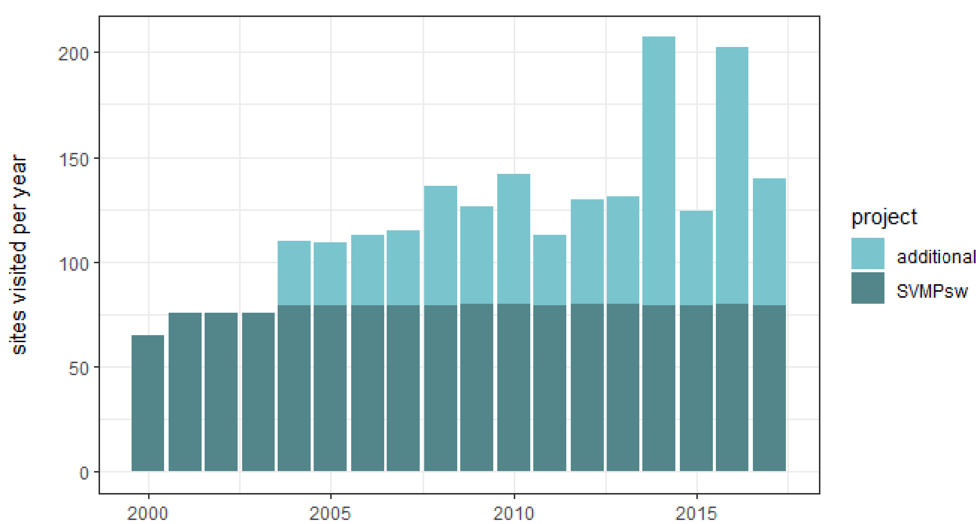


Figure 3: Number of sites visited per year as part of the soundwide estimate and additional sample effort.

Figure 4 shows the number of unique sites visited over time. Throughout the first 18 years of the monitoring program, we have visited 652 different sites, which is more than 25% of all potential sample sites in greater Puget Sound.

Because of the uneven distribution of native seagrasses in greater Puget Sound, and the way monitoring effort is allocated, these sites contain over 45% of all native seagrass in greater Puget Sound. On average, we visited about 30 new sites every year. In 2014 and 2016 there is a big bump in the number of new sites visited, due to the additional interagency agreements.

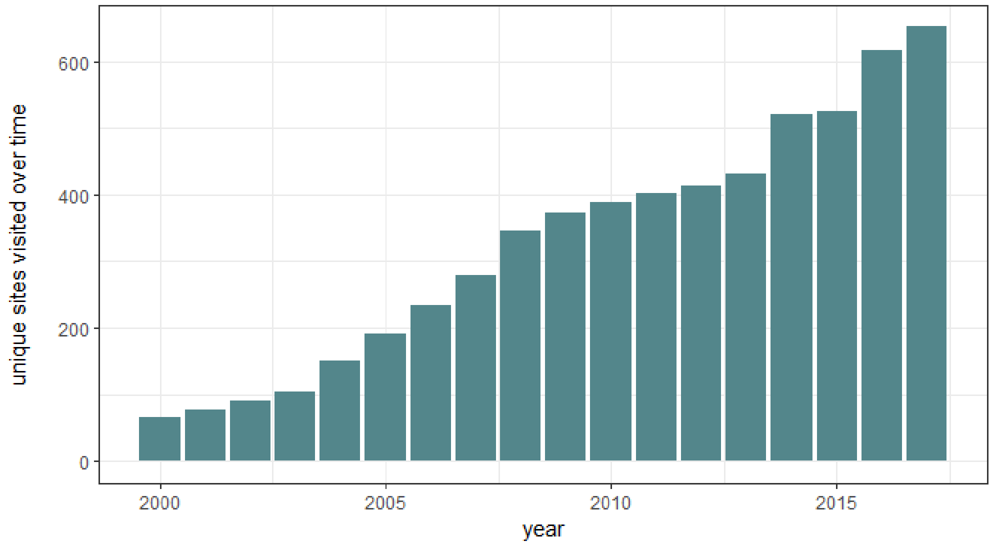


Figure 4: Cumulative count of unique sites visited over time

The majority of all sites were sampled less than 3 years. These sites represent our efforts to establish the distribution of seagrass along large stretches of shoreline (Figure 5). There is also a disproportionately large number of sites that were sampled for 6 years in the dataset. This is a consequence of the statistical design for the soundwide estimate.

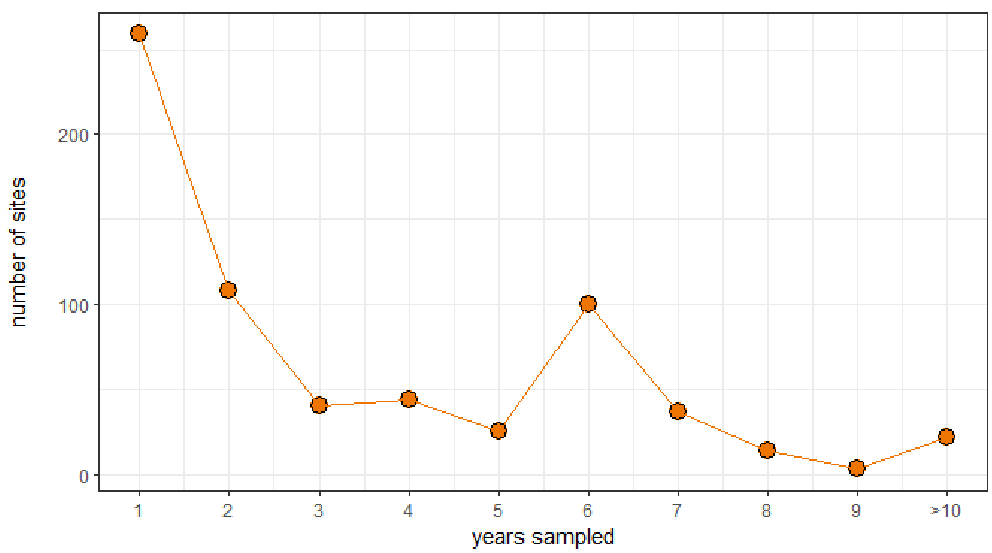


Figure 5: Distribution of the number of years individual sites were sampled.

Between 2000 and 2014, sites for the soundwide estimate were selected randomly with 20% rotation (sites were sampled for 5 consecutive years before they were rotated out of the sample pool). In 2015, we changed the statistical design for the soundwide estimate to a 3 year rotating panel design, in which we repeat all sites sampled in 2004, 2009 and 2014 on a rotating basis. As of 2017, each panel has been resampled once, hence the large number of sites sampled for 6 years. Approximately 75 sites were sampled for 7 years or longer. These sites are either part of the core and persistent flats stratum, or are sites of particular interest.

In total we have sampled approximately 21% of the shoreline of greater Puget Sound. Figure 6 and Figure 7 show the distribution of our sampling effort across different counties bordering greater Puget Sound. Kitsap and Whatcom counties have the most intensively sampled shorelines in greater Puget Sound as a result of interagency agreements with the City of Bellingham, the Suquamish Tribe and the City of Bainbridge Island. It is interesting to note that as of 2017, the two counties with the largest population size (King County and Pierce County) have been under-sampled. However, DNR sampled the entire shoreline of King County as part of an interagency agreement in 2018. We also plan to increase sampling effort along the shoreline of Pierce County in the near future. Note that Thurston County is not included in this analysis. The majority of shorelines in Thurston County are unsuitable for native seagrasses due to the large tidal range in the terminal inlets of South Puget Sound.

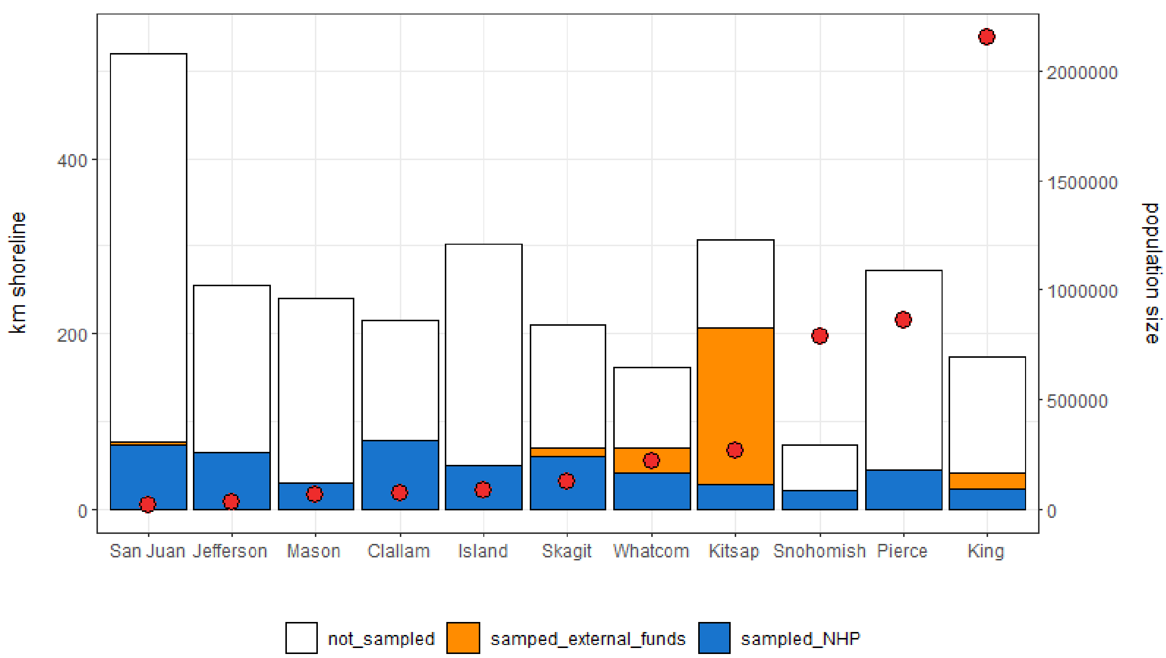


Figure 6: Relative length of shoreline sampled in each county. Blue indicates the length of shoreline sampled using funds allocated to the SVMP. Orange represents the length of shoreline sampled using external funds, including DNR's Aquatic Reserves Program, and interagency agreements with local governments and Tribes. The red dots indicate the size of the human population in each county (data from 2017).

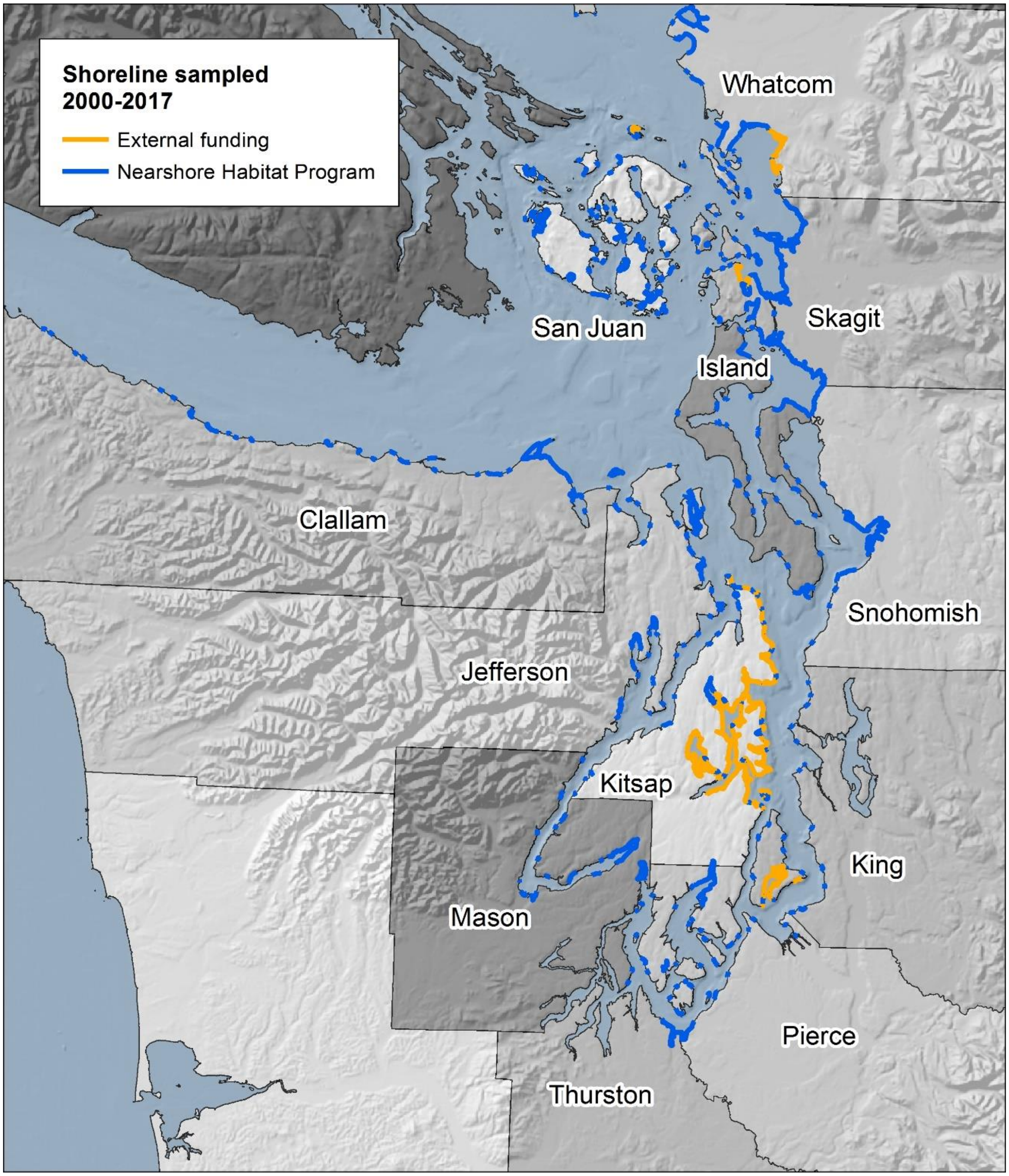


Figure 7: Shoreline sampled across greater Puget Sound. Blue indicates the length of shoreline sampled using funds allocated to the SVMP. Orange represents the length of shoreline sampled using external funds, including DNR's Reserves Program, and interagency agreements with local governments and Tribes.

3.1.2 SVMP sample effort in 2016 and 2017

The SVMP resampled the panel years from 2009 (80 sites) and 2014 (79 sites) to estimate soundwide seagrass area in 2016 and 2017. Sites were sampled using two sets of transects: SRS (an exact repeat of transects sampled in 2009 or 2014) and STR (new transects, selected using a stratified random approach, to better estimate change going forward). In 2016, we sampled 29 sites of interest using SRS, STR or SYS transects as part of special studies. An additional 95 sites were sampled with STR transects for the Suquamish Tribe and the City of Bainbridge Island (Table 2). In 2017, we sampled an additional 42 sites as part of special studies. The DNR Aquatic Reserves Program funded an additional 21 sites in Quartermaster Harbor.

Table 2: Sites sampled in 2016 and 2017, including funding source and transect type

SVMP sample effort 2016-2017			
Study	Transect type	2016	2017
SVMPsw	SRS & STR	80	79
Special studies	SRS, STR or SYS	29	42
Suquamish	STR	71	0
Bainbridge	STR	24	0
Reserves	STR	0	21

The 2016 and 2017 sample effort combined cover 13.17% of all potential sample sites in greater Puget Sound. We sampled 48.6% of all flats, 11.7% of all narrow fringe and 12.9% of all wide fringe sites. In total, we sampled 2035 SRS transects, 3690 STR transects, and 175 SYS transects in 2016 and 2017. Data from the Suquamish and Bainbridge Island studies are described in detail in Christiaen et al. 2017, and Christiaen et al. 2018.

3.2 Results based on all SVMP data 2000-2017

3.2.1 Seagrass species in greater Puget Sound

The SVMP is designed to estimate status and trends of native seagrasses, but is largely focused on *Zostera marina* (eelgrass), the most abundant seagrass species in greater Puget Sound. Eelgrass is widespread throughout the study area (Figure 9 and Figure 10). It was found in over 78% of sites sampled as part of the SVMP. Hood Canal and the Saratoga-Whidbey Basin have the highest frequency of occurrence (eelgrass present in ~95% of all sites sampled), while Central Puget Sound has the lowest frequency of occurrence (eelgrass present in ~69% of all sites sampled). Eelgrass does not occur in the extreme reaches of southern Puget Sound and Liberty Bay, and is relatively sparse in Sinclair Inlet, Dyes Inlet, and Bellingham Bay. Eelgrass grows mostly on sandy and muddy substrates, and is found between +1.4m and -12.5m relative to MLLW in greater Puget Sound. The plants are morphologically plastic: canopy height ranges from less than 40 cm all the way up to 2m, depending on the depth and the location in Puget Sound.

Figure 8 A. A small patch of non-native *Zostera japonica*, surrounded by the native *Zostera marina*. *Z. japonica* is usually smaller than *Z. marina*. At some locations it is difficult to differentiate between both species based on size alone. B. Long strap-like leaves *of Phyllospadix scouleri*.

The non-native *Zostera japonica* is generally a lot smaller than *Zostera marina* (Figure 8A). However, it can be difficult to distinguish both species based on size alone. The SVMP classifies presence/absence *of Zostera japonica* from video observations, but at sites where we suspect this species to be present, we usually take a number of grab samples to confirm our observations based on the morphology of the leaf sheath and the root system. *Zostera japonica* grows at higher tidal elevations than *Z. marina*, and is often too shallow for the sample vessel. As such, our data do not capture the full extent of *Z. japonica*. Nevertheless, the data suggests that *Z. japonica* is common in Northern Puget Sound, Hood Canal, The Saratoga Whidbey Basin and Central Puget Sound (Figure 9 and Figure 11).

There is no *Zostera japonica* along the Strait of Juan de Fuca and it is rare in the San Juan Islands. While we have evidence of the presence of *Zostera japonica* in South Central

Puget Sound (for example near Tolmie State Park), *Zostera japonica* was not commonly observed in sites sampled as part of the SVMP in this area. One exception is Henderson Bay at the head of Carr Inlet. Recent surveys (2014-2017) have documented *Z. japonica* in 7 sites at this location. *Zostera japonica* usually occurs at sites where *Z. marina* is present: in 171 out of 178 sites with *Z. japonica*, *Z. marina* was also present. This suggests that both species have similar requirements in terms of habitat and substrate.

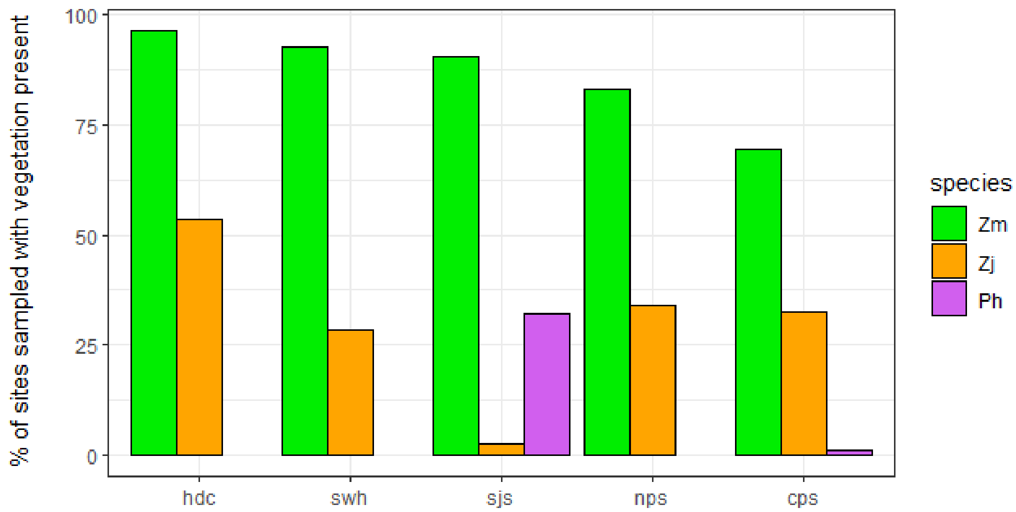


Figure 9: The percentage of sites where *Zostera marina*, *Zostera japonica* and *Phyllospadix spp.* were detected in each region during sampling for the SVMP.

There are 3 species of P*hyllospadix* (or surfgras) in Washington State: *Phyllospadix torreyi*, *Phyllospadix scouleri (*Figure 8B*)* and *Phyllospadix serrulatus*. Only *P. scouleri* and *P. serrulatus* are observed in greater Puget Sound. These plants are mostly found on hard substrate and along the exposed rocky coasts of the San Juan Islands and the Strait (Figure 12). *P. serrulatus* can also grow amongst cobbles covered with sediment and is sometimes intermixed with *Z. marina*. These species are difficult to distinguish based on underwater videography, and some misidentification is possible. Grab samples are used to make definitive identifications in many cases. Distinguishing characteristics of *Phyllospadix* include the long-strap like leaves, and the different morphology of the root system.

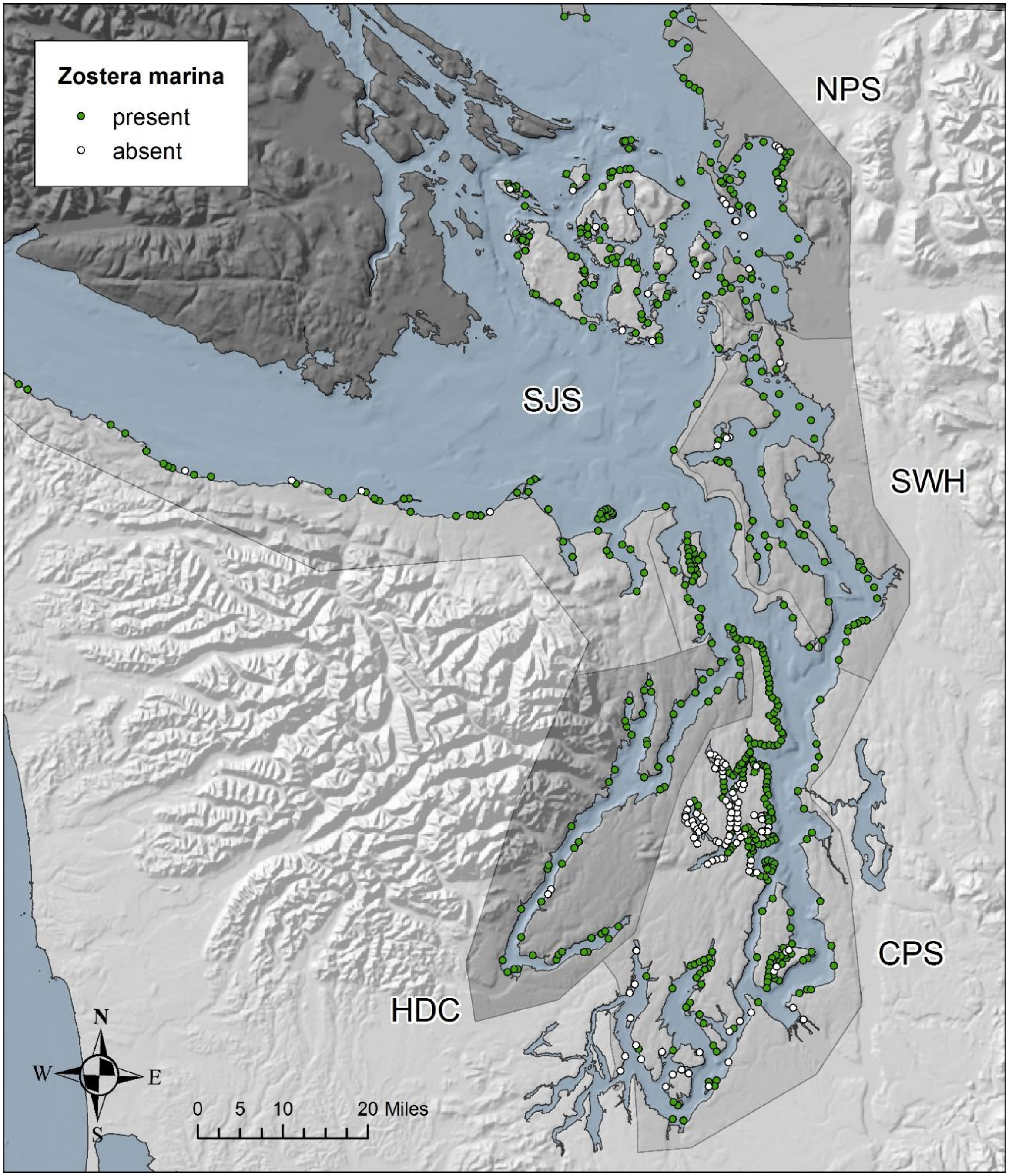


Figure 10: The presence of *Zostera marina* at sites sampled for the SVMP between 2000 and 2017.

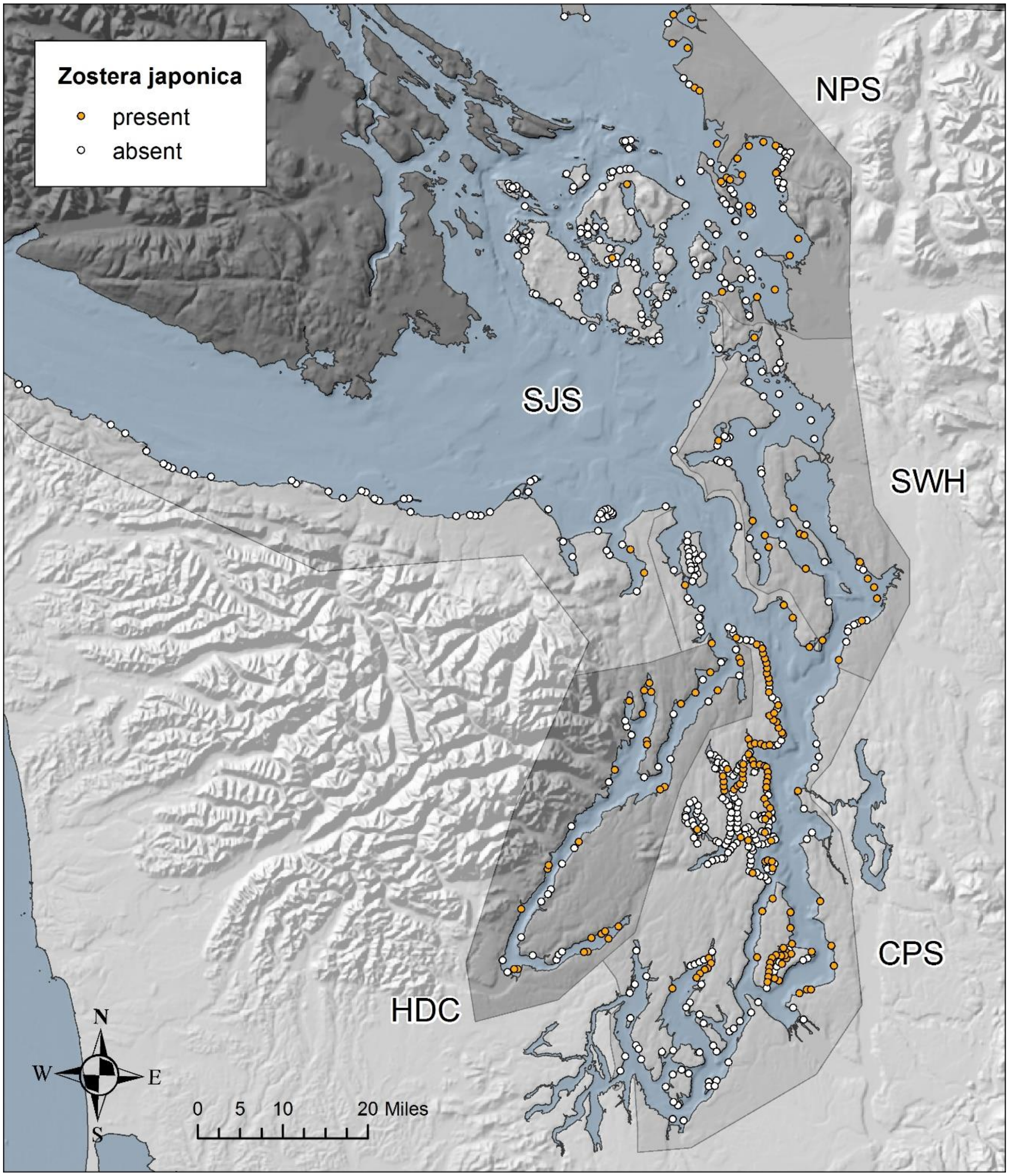


Figure 11: The presence of *Zostera japonica* at sites sampled for the SVMP between 2000 and 2017.

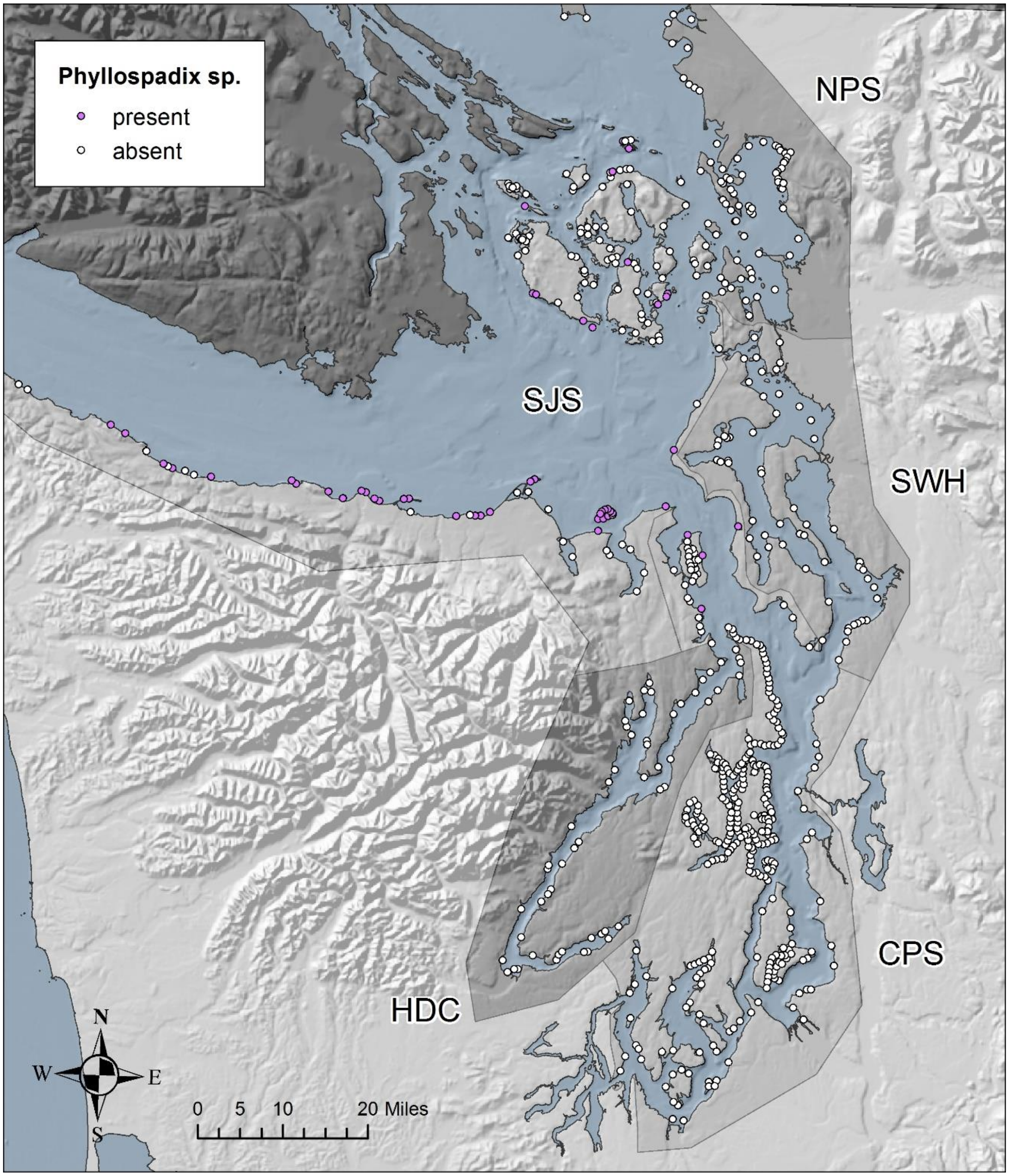


Figure 12: The presence of *Phyllospadix spp*. at sites sampled for the SVMP between 2000 and 2017

3.2.2 Spatial patterns in seagrass distribution

3.2.2.1 Spatial distribution of native seagrass in greater Puget Sound

Native seagrass (predominantly eelgrass) has a distinct spatial distribution in greater Puget Sound, which is in part determined by the distribution of available habitat (Figure 14). Seagrass beds in greater Puget Sound have a skewed size distribution. Approximately 50% of all native seagrass is found on 74 tidal flats, and the remaining 50% grows on a large number of smaller fringe sites in a narrow band along the shoreline. In Northern Puget Sound and the Saratoga Whidbey Basin the majority of seagrass is found on tidal flats. In Hood and Central Puget Sound the majority of seagrass is found on fringe sites (Figure 14). The largest seagrass beds are found on tidal flats in Padilla and Samish Bay. These two locations contain more than 20% of all native seagrass in greater Puget Sound. Other flats with large seagrass beds are Skagit Bay, Fidalgo Bay, Jamestown (near Dungeness Bay), Lummi Bay, Birch Bay, Drayton Harbor, Salmon Bank, the Snohomish Delta, Cultus Bay, Quilcene Bay, Dosewallips flats, and Lynch Cove[3]. There are only a few flats sites that have very little native seagrass relative to their respective size (Figure 13). These sites include the tide flats of the Nooksack delta, inner Quartermaster Harbor and Westcott Bay. The former is probably influenced by the glacial till laden waters from the Nooksack River, while the latter two sites are locations with documented seagrass declines.

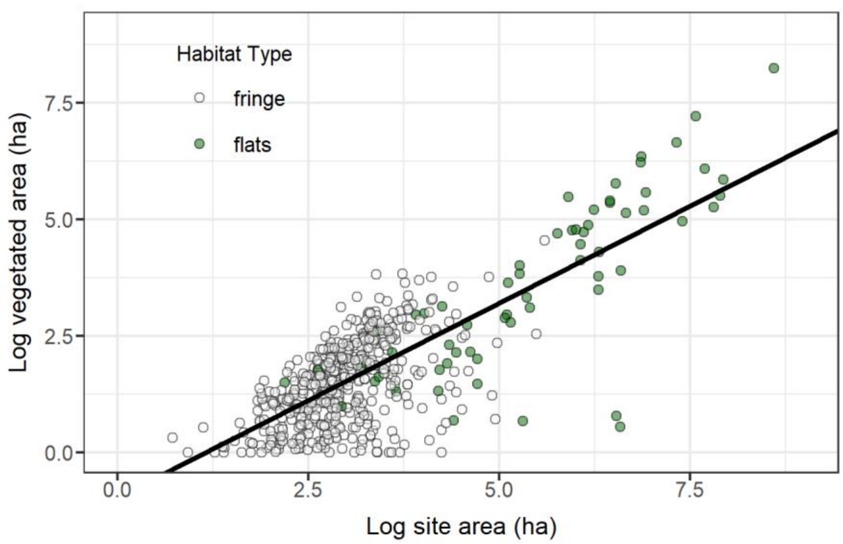


Figure 13: The size of native seagrass beds vs the total area of substrate available at individual sites sampled in greater Puget Sound. Both axis are log-transformed (natural log), Flats are indicated in green and fringe sites are indicated in grey.

[3] Note that this list is not exhaustive. Not all tide flats with native seagrass have been sampled by the SVMP (for example Port Susan).

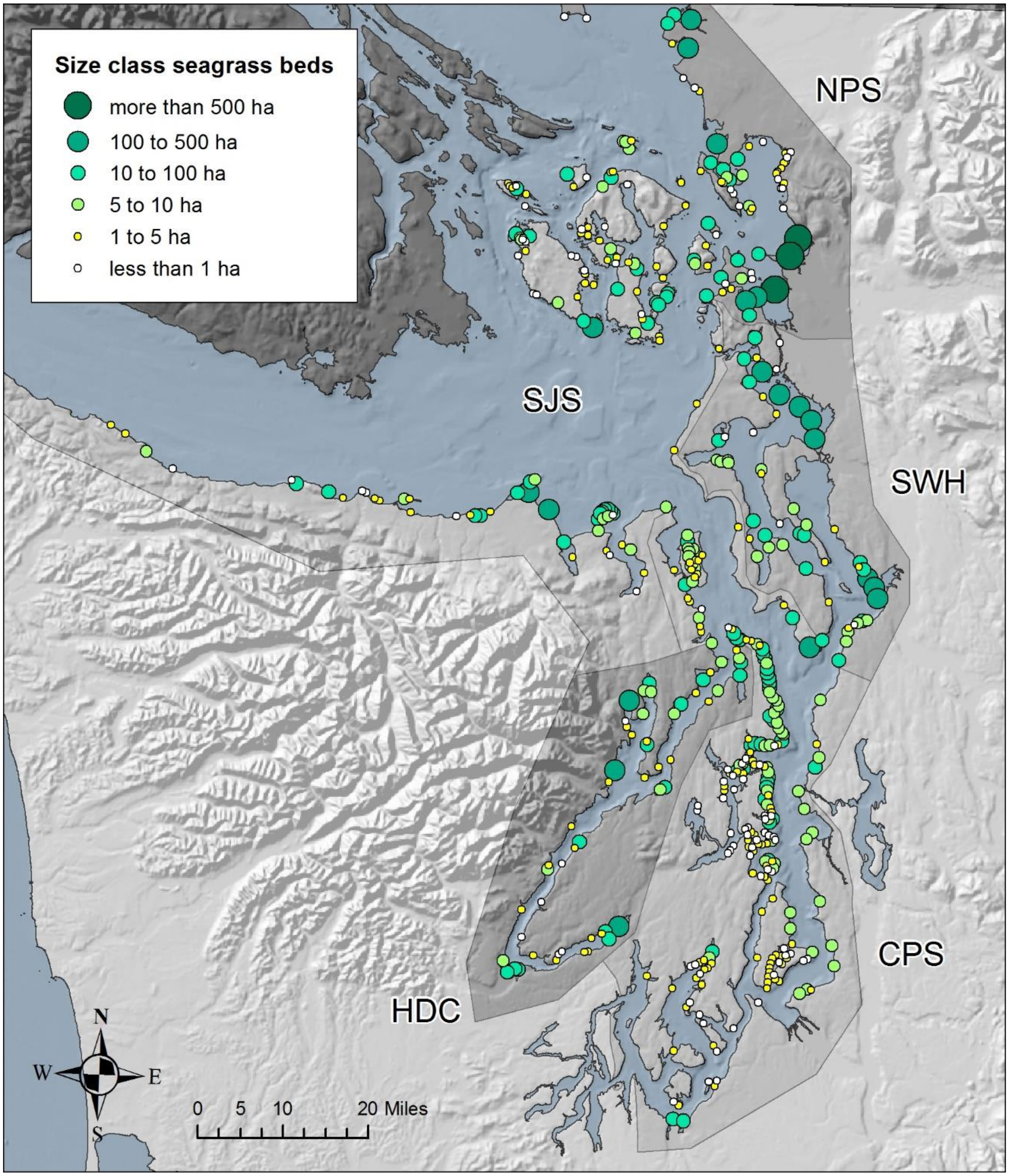


Figure 14: Size distribution of native seagrass beds at sites sampled between 2000 and 2017. Larger symbols and darker colors indicate larger seagrass beds.

3.2.2.2 Depth distribution of native seagrass in greater Puget Sound

Native seagrasses have been observed as shallow as 1.4m (MLLW) and as deep as -12.5m (MLLW) in greater Puget Sound. The majority of native seagrass occurs between 0 and -4m relative to MLLW (Figure 15, Figure 16). There is a large scale spatial pattern in seagrass depth distribution in greater Puget Sound. Native seagrass (predominantly eelgrass) tends to grow deepest near the Strait, the San Juan Islands, and the northern portion of Central Puget Sound (Figure 17). It does not grow as deep in South Central Puget Sound, the Saratoga Whidbey Basin and bays and inlets with lower flushing, such as Penn Cove, Kilisut Harbor, and Quartermaster Harbor.

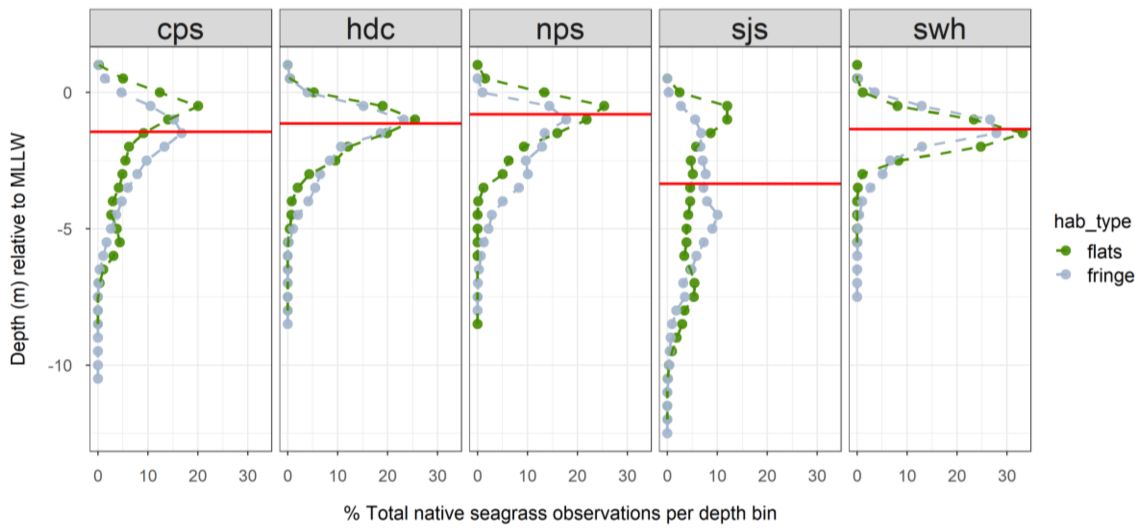


Figure 15: Depth distribution of native seagrass in greater Puget Sound, calculated as the % of total seagrass observations per 0.5m depth bins, split per region and per habitat type (flats in green and fringe in grey). The red line indicates the median depth of native seagrass in each of the 5 regions of greater Puget Sound.

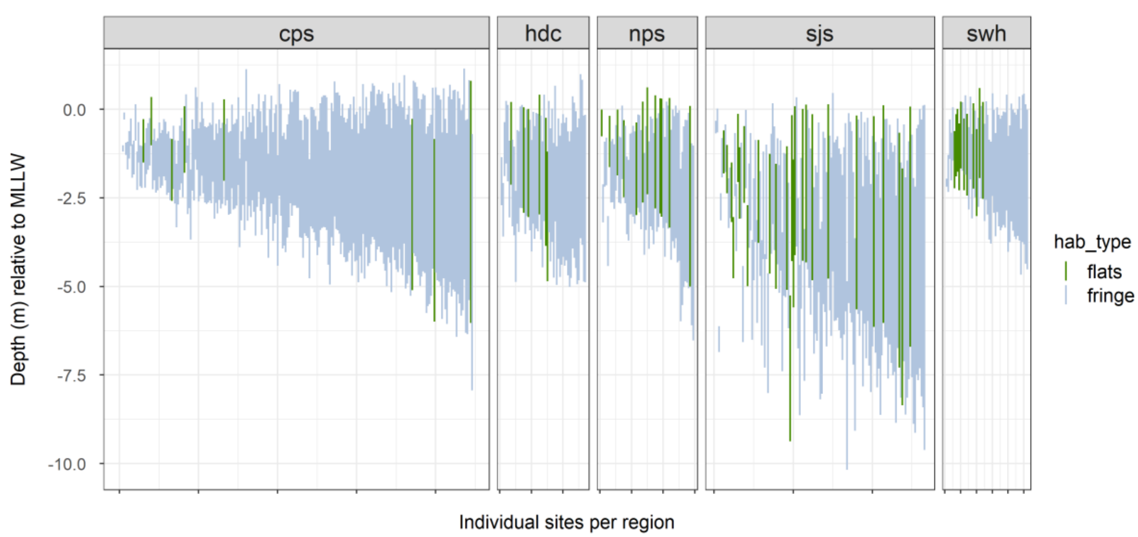


Figure 16: Depth range of native seagrass beds at individual sites, calculated as the difference between the 97.5th percentile and the 2.5th percentile of all depth observations of native seagrass at individual sites, pooled over all transects and all years. Sites have been sorted by increasing depth range in each of the 5 regions of greater Puget Sound.

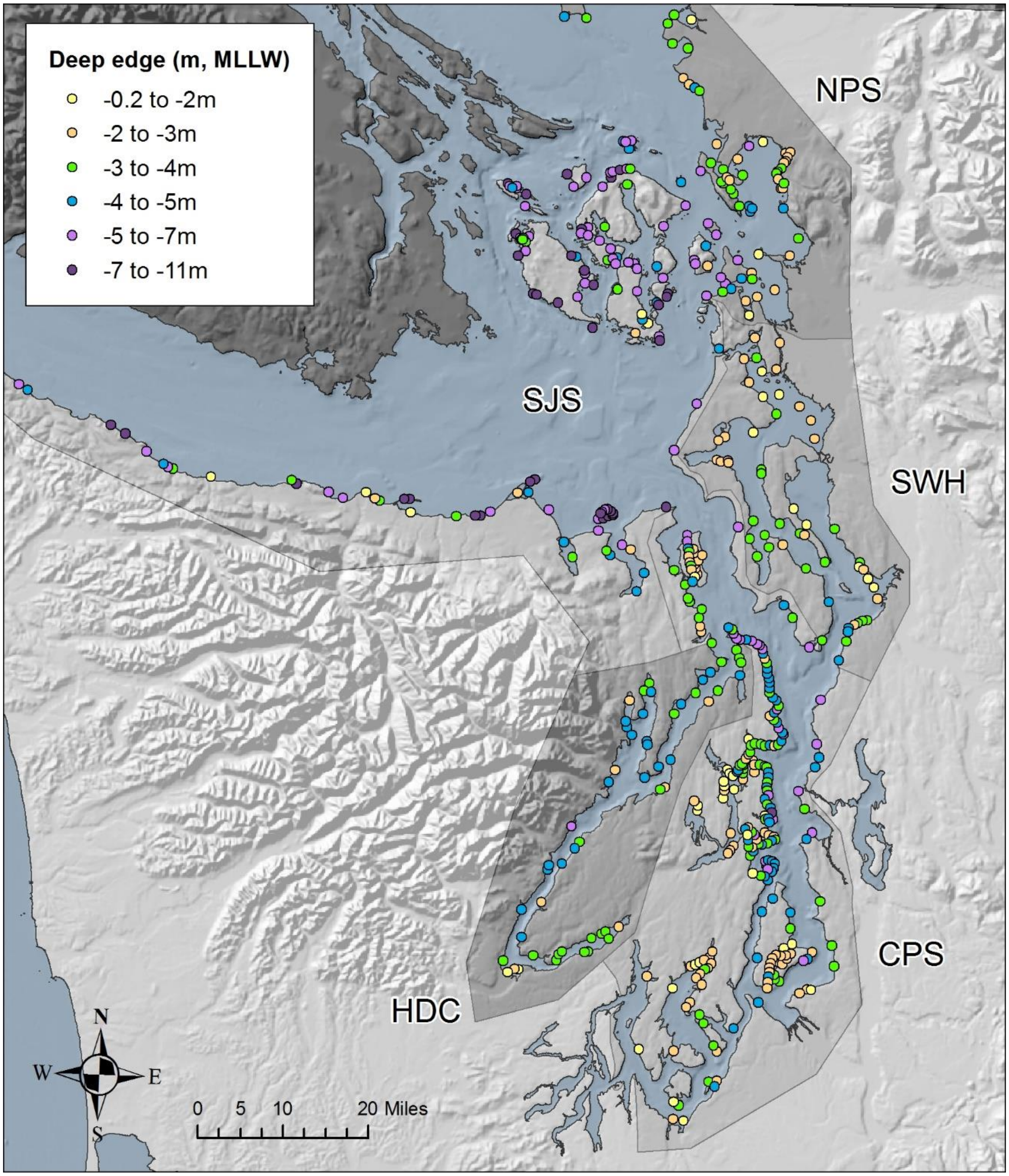


Figure 17: The deep edge of native seagrass beds at sites sampled between 2000 and 2017. The deep edge was calculated as the 2.5th percentile of all depth observations of eelgrass and surfgrass at individual sites, pooled over all transects and all years.

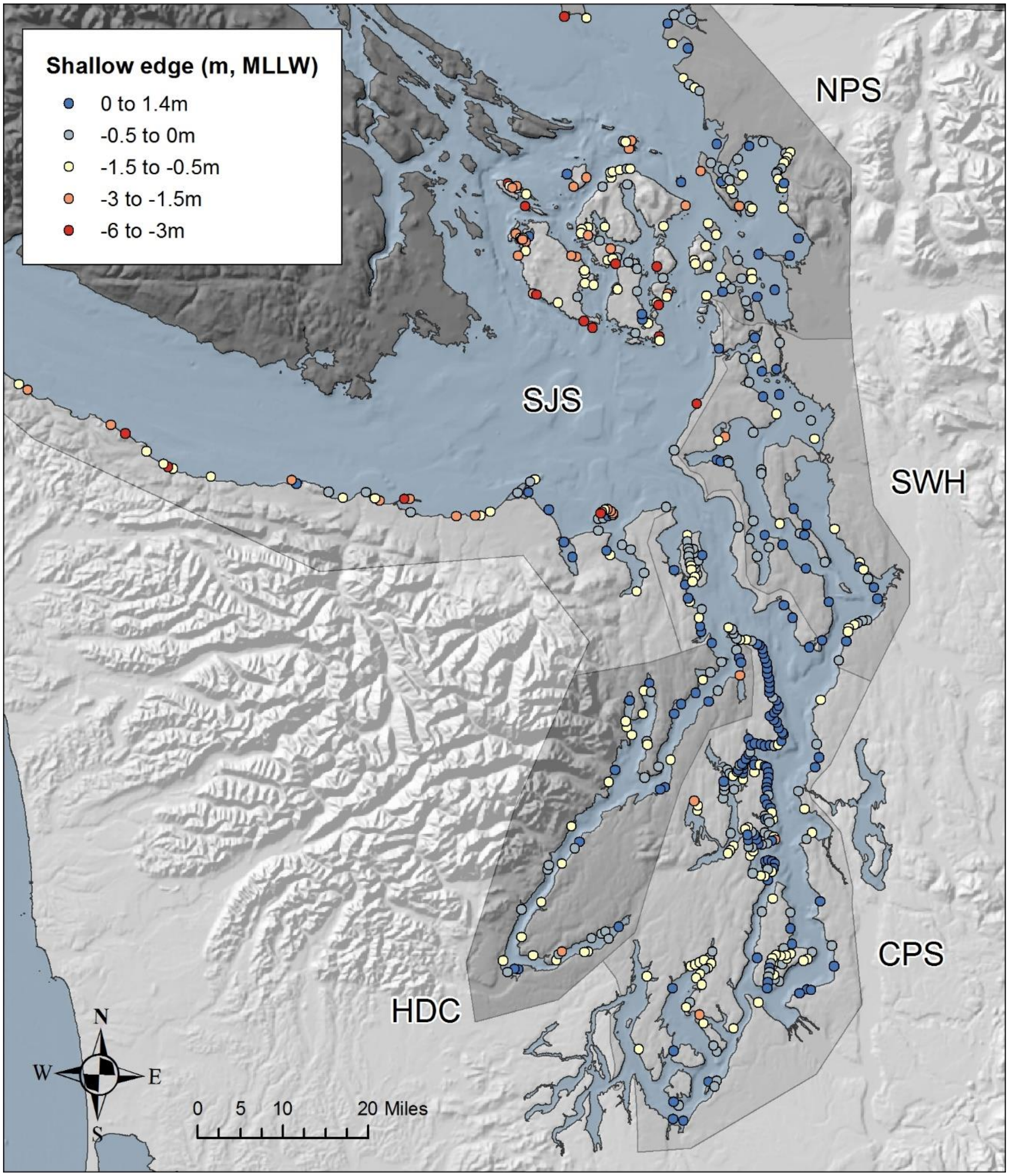


Figure 18: The shallow edge of native seagrass beds at sites sampled between 2000 and 2017. The shallow edge was calculated as the 97.5th percentile of all depth observations of eelgrass and surfgrass at individual sites, pooled over all transects and all years.

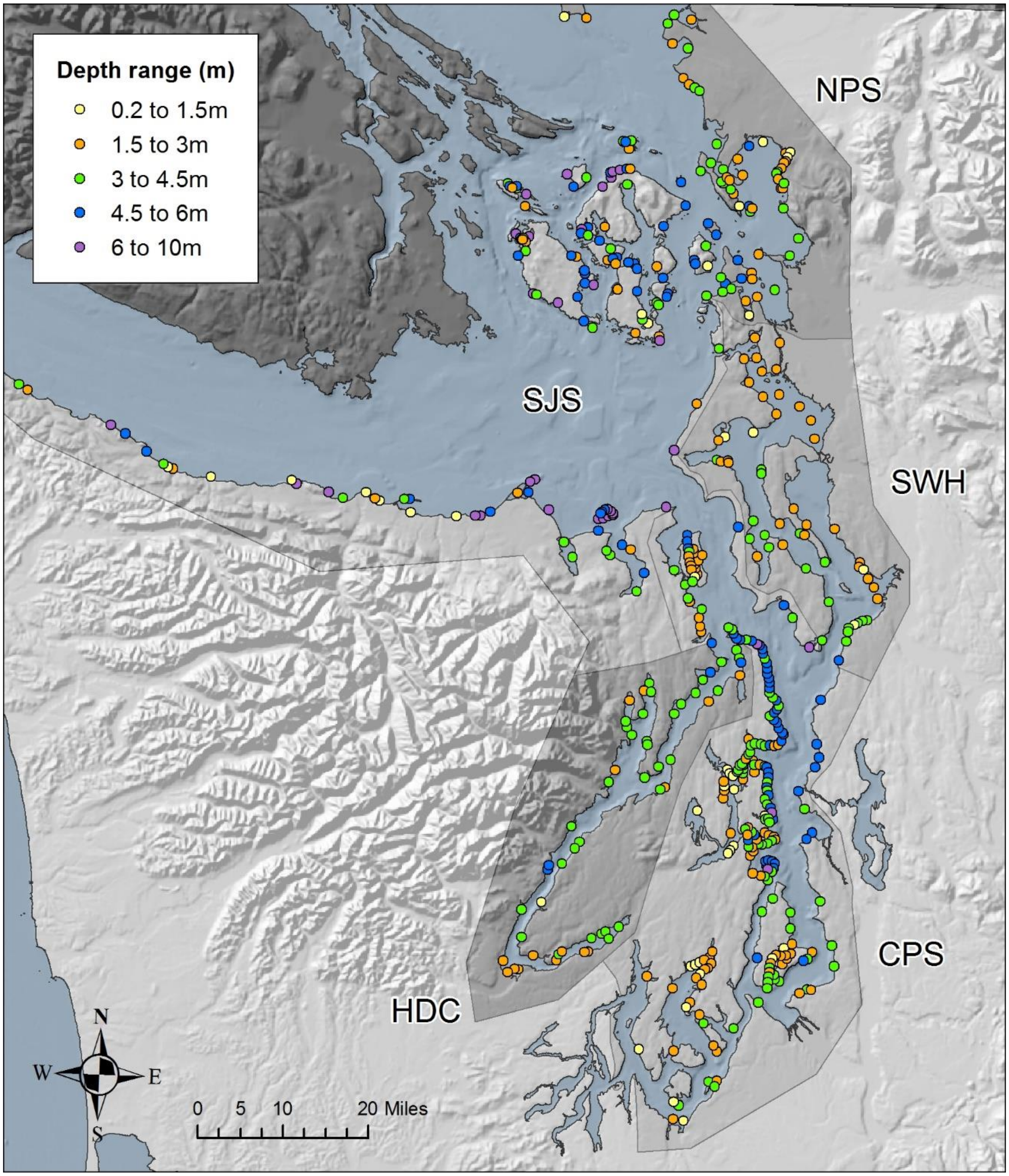


Figure 19: The depth range of native seagrass beds at sites sampled between 2000 and 2017. The seagrass depth range was calculated as the difference between the 97.5th percentile and the 2.5th percentile of all depth observations of eelgrass and surfgrass at individual sites, pooled over all transects and all years.

Native seagrass grows further up in the intertidal in Puget Sound proper as compared to the San Juan Islands and the Strait (Figure 18). However, there is a lot of variability between individual sites. Figure 16 and Figure 19 show the seagrass depth range, which is the width of the band where native seagrass was observed at individual sites, calculated as the difference between the 2.5th and 97.5th percentiles of depth observations of eelgrass and surfgrass at individual sites. Again, there is a lot of variability in depth range, both among individual sites and among the different regions. In addition there are a number of gradients in depth range within regions (from N to S in Central Puget Sound) and at the scale of individual bays and inlets (Quartermaster Harbor, Kilisut Harbor, Port Orchard). These spatial patterns are likely caused by a combination of different factors, including the latitudinal gradient in tidal range in Puget Sound, and the lower water clarity at sites influenced by glacial rivers. At a number of enclosed embayments with lower flushing, such as Quartermaster Harbor, seagrass beds are likely impacted by low water quality. We have also documented a number of sites where seagrass is likely impacted by green macroalgae, such as Yukon Harbor.

3.2.3 Soundwide seagrass area

Figure 20 shows annual estimates of soundwide seagrass area relative to a baseline calculated from data between 2000 and 2008. Soundwide seagrass has remained relatively stable over the time period of the SVMP. This is consistent with a long-term study on eelgrass in the herring spawn areas in Puget Sound (Shelton et al. 2016). The uncertainty represented in error bars is mainly due to practical limitations on sample effort, and the skewed size distribution of seagrass beds in greater Puget Sound (Figure 14). The annual soundwide area estimates are not sufficiently precise to assess progress toward the 2020 target.

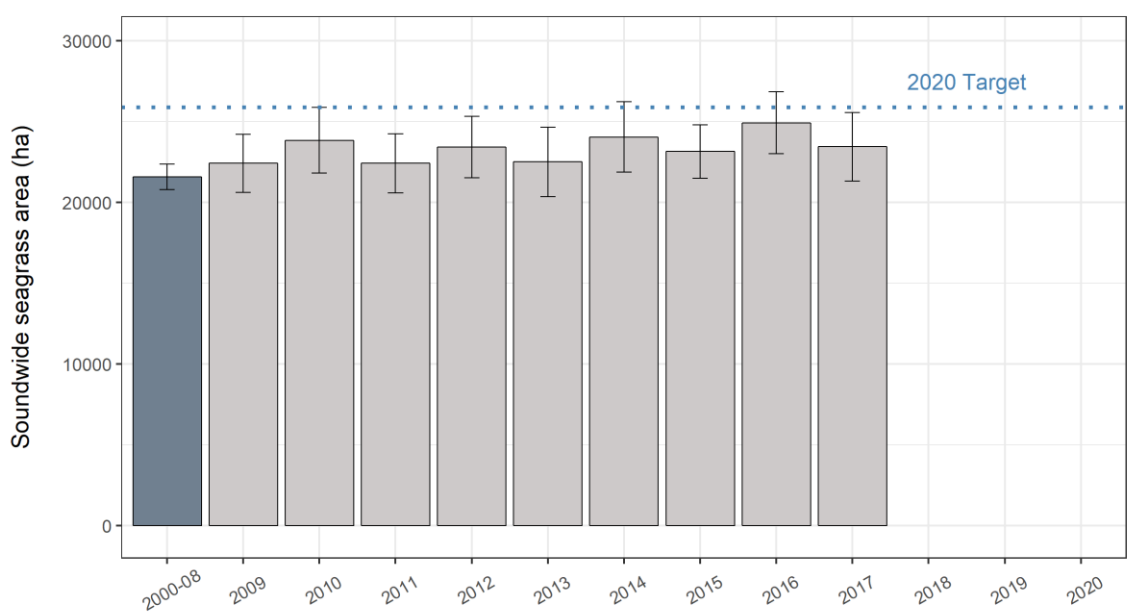


Figure 20: Annual estimates of soundwide seagrass area relative to a baseline in greater Puget Sound. Error bars are standard error.

To more precisely assess if soundwide seagrass area met the 2020 target set by the Puget Sound Partnership, we calculated soundwide seagrass area based on the 3-panel estimates of 214 independent sites (Figure 21). The 3 year soundwide seagrass area estimates appear larger, but were not significantly different from the 2000-2008 baseline. The 3-year averages are significantly lower than the 2020 target.

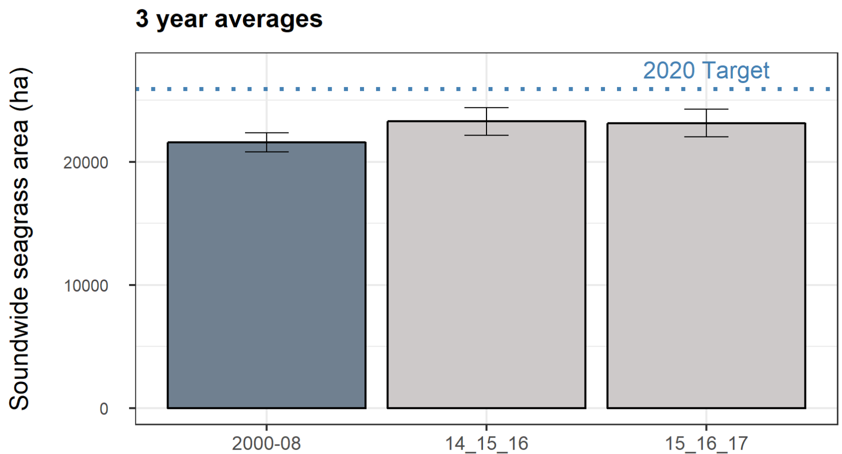


Figure 21: 3 year panel estimates of soundwide seagrass area vs the 2000-2008 baseline (mean ± SE).

3.2.4 Site trends all data

To determine trends at the site level, we combined results from a linear regression on the annual estimates of site seagrass area over time (inversely weighted by variance), a paired transect analysis for sites sampled in 2009 and 2016 as well as 2014 and 2017 (see section 3.3.2), and a visual assessment of the spatial conformation of the seagrass beds over time.

To assess long-term trends, we identified sites with at least 2 years of data where at least 1 year was sampled before 2013, and where there was at least a period of 5 years between the initial and the final sample. For recent trends we identified sites that have been sampled at least twice between 2013 and 2017.

Since 2000, the SVMP has monitored seagrass at 652 different sites in greater Puget Sound (over 25% of all potential sample sites in the study area). At 525 sites there was native seagrass (*Zostera marina* or *Phyllospadix*) present. Out of these sites, 199 showed no long-term trend, 43 sites experienced long-term increases, and 34 sites showed long-term declines. At 249 sites there was not enough data to assess long-term trends (Table 3). At 361 sites there was not enough data to assess short term, 5-year trends. Of the remaining sites, 115 showed no recent trend, 23 sites experienced recent increases, and 26 sites had recent declines (Table 3).

Table 3: Long-term, and recent 5-year trends for all sites sampled as part of the SVMP. Note that these sites do not represent a random sample of the Sound as non-randomly selected data have been pooled with randomly selected data.

Long-term trends				
region	decline	increase	no trend	limited data
CPS	14	10	50	149
HDC	5	10	32	7
NPS	4	5	14	36
SJS	10	9	70	47
SWH	1	9	33	10
TOTAL	34	43	199	249

Recent 5-year trends				
region	decline	increase	no trend	limited data
CPS	8	9	40	166
HDC	6	3	13	32
NPS	3	3	10	43
SJS	6	6	39	85
SWH	3	2	13	35
TOTAL	26	23	115	361

Figure 22 shows the number of sites with increases and declines per size class. When you look at long-term trends, there are more increases than declines at sites with large seagrass beds, while there are more declines than increases at sites with small seagrass beds. The same pattern occurs when recent 5-year trends are assessed, but it is less pronounced.

Note that these numbers do not represent a random sample of sites in greater Puget Sound. They are a summary for all site sampled as part of the SVMP and include both the sites from the soundwide study (which are randomly selected) and sites from additional studies, which are often focused on a particular region. We cannot extrapolate based on these numbers to assess the condition of Puget Sound as a whole. However, these data can be used to assess spatial patterns in site level increases and declines throughout the Sound.

Sites with long-term declines were mostly clustered near the San Juan Islands, in lower Hood Canal, in south central Puget Sound, and at locations with reduced flushing, such as the ends of Carr and Case Inlet, Westcott Bay, the southern end of Fidalgo Bay, and Quartermaster Harbor (Figure 23 and Table 4). Sites with long-term increases were mostly located in the Saratoga-Whidbey Basin and Hood Canal. Between 2013 and 2017, the spatial pattern was relatively similar. We documented recent declines in south Central Puget Sound and near the San Juan Islands and the Guemes Channel, and recent increases near Admiralty Inlet and on the eastern shore of Central Puget Sound (Figure 24 and Table 5). Nevertheless, there are some differences when comparing both maps.

Figure 22: Number of sites with increases or declines in seagrass area per size class. At larger sites there are more long-term increases than long-term declines. At smaller sites there are more long-term declines. During the recent 5 years, there is a similar pattern, but less pronounced.

Some sites have different trends depending on the time period of interest. For example, the seagrass beds on the Skokomish River Delta showed a marked increase between 2005 and 2013, but have been declining since. Seagrass beds on the Nisqually River Delta have no significant long-term trend but experienced a recent decline due to an extreme weather event in 2017. Several sites experienced declines early in the time series, but have been more stable since (core006, cps1967, flats53, hdc2338, hdc2344, sjs0635). Other sites increased earlier in the time-series, but have stabilized since (such as swh0955). It is also important to note that increases/declines do not necessarily happen evenly throughout a site. Several sites have increases/declines at different locations within the site or at different depth (See sections 3.3.2.4 and 3.3.3).

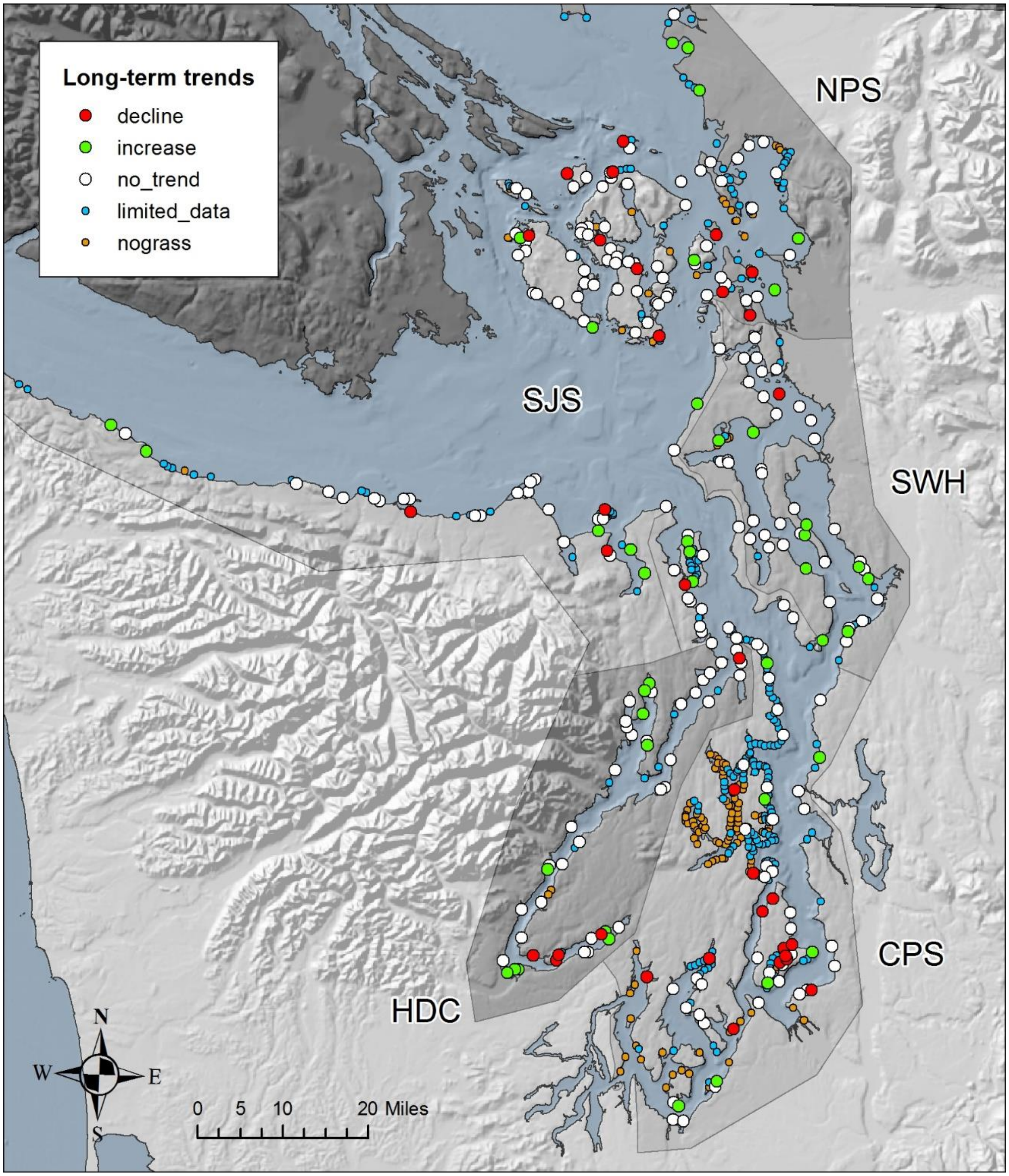


Figure 23: Long term trends for all sites sampled between 2000 and 2017 by the SVMP.

Table 4: Summary of sites with long-term increases or declines.

site_code	site_name	region	hab_type	start	end	years sampled	long_term_trend
core005	Dumas Bay, Federal Way	cps	fringe	2000	2017	18	decline
core006	Burley Spit, Henderson Bay	cps	fringe	2000	2017	18	decline
cps1046	Battle Point North, Bainbridge	cps	fringe	2000	2014	5	decline
cps1137	Southwest Cove Rd, Vashon	cps	fringe	2011	2017	5	decline
cps1141	NE of Fern Cove, Vashon	cps	fringe	2008	2016	6	decline
cps1160	Portage, Vashon	cps	fringe	2006	2016	7	decline
cps1180	NW of Dockton Park, Maury Island	cps	fringe	2008	2017	2	decline
cps1182	Vashon Golf & Country Club	cps	fringe	2004	2017	2	decline
cps1186	Camp Burton, Vashon	cps	fringe	2004	2017	2	decline
cps1967	Sunshine Beach, Vaughn	cps	fringe	2004	2016	10	decline
cps2068	NE of Point Fosdick, Gig Harbor	cps	fringe	2009	2016	6	decline
cps2105	Yukon Harbor, Port Orchard	cps	fringe	2009	2016	6	decline
cps2552	Oak Bay Ramp, Oak Bay	cps	fringe	2007	2016	6	decline
flats33	Quartermaster Harbor, Vashon	cps	flats	2004	2017	4	decline
cps0046	East Indian Island	cps	fringe	2007	2017	3	increase
cps1069	Murden Cove, Bainbridge	cps	fringe	2003	2015	7	increase
cps1118	N of Neill Point, Vashon	cps	fringe	2000	2017	5	increase
cps1164	Leuna Beach, Maury Island	cps	fringe	2002	2015	6	increase
cps1277	Thompson Cove, Anderson Island	cps	fringe	2003	2015	6	increase
cps1676	SW of Bitter Lake, Broadview	cps	fringe	2005	2016	6	increase
cps1820	Gordon Point, Steilacoom	cps	fringe	2004	2015	6	increase
cps2218	Pilot Point, Manette Peninsula	cps	fringe	2002	2015	7	increase
cps2555	E of Oak Bay Ramp, Oak Bay	cps	fringe	2007	2012	2	increase
flats46	Kilisut Harbor	cps	flats	2007	2017	4	increase
hdc2239	SW of Buck Lake, Kingston	hdc	fringe	2002	2015	7	decline
hdc2338	S of Wildberry Lake, Tahuya	hdc	fringe	2000	2015	11	decline
hdc2344	East of Wheeler Lake, Tahuya	hdc	fringe	2003	2017	10	decline
hdc2345	SE of Jiggs Lake, Tahuya	hdc	fringe	2000	2010	4	decline
hdc2355	Stimson Creek, Belfair	hdc	fringe	2005	2010	2	decline
flats43	Tarboo Bay	hdc	flats	2000	2015	8	increase
hdc2356	NE of Stimson Creek, Belfair	hdc	fringe	2005	2016	6	increase
hdc2359	SW Lynch Cove, Belfair	hdc	fringe	2000	2016	12	increase
hdc2380	Skokomish Flats East	hdc	fringe	2005	2017	7	increase
hdc2381	Skokomish Flats West	hdc	fringe	2005	2017	7	increase
hdc2383	Indian Hole, Anna's Bay	hdc	fringe	2004	2015	7	increase
hdc2408	Jorsted Creek South	hdc	fringe	2009	2016	8	increase
hdc2460	Lindsays Beach, Quilcene	hdc	fringe	2007	2016	6	increase
hdc2465	SW of Long Spit, Quilcene	hdc	fringe	2004	2015	6	increase
hdc2479	S of Tabook Point, Toandos Peninsula	hdc	fringe	2004	2015	7	increase
flats16	Fidalgo Bay South	nps	flats	2008	2016	7	decline
nps0059	Sinclair Island SW	nps	fringe	2000	2015	8	decline
nps0670	Boat Harbor South, Guemes Island	nps	fringe	2004	2015	6	decline
nps1487	Loverick's, Anacortes	nps	fringe	2008	2016	7	decline
core001	Padilla Bay, Mount Vernon	nps	flats	2001	2017	17	increase
flats03	Birch Bay	nps	flats	2009	2016	6	increase
flats11	Samish Bay N	nps	flats	2001	2017	17	increase
nps1328	NW of Birch Bay, Blaine	nps	fringe	2007	2016	6	increase
nps1344	SW of Lake Terrell, Ferndale	nps	fringe	2005	2016	6	increase
flats53	Westcott Bay, San Juan Island	sjs	flats	2000	2012	6	decline
flats62	Swifts Bay, Lopez Island	sjs	flats	2001	2015	6	decline
flats66	Shallow Bay, Sucia island	sjs	flats	2003	2016	7	decline
sjs0081	Broken Point, Shaw Island	sjs	fringe	2000	2015	10	decline
sjs0351	North Bay S, Waldron Island	sjs	fringe	2001	2015	7	decline
sjs0454	Point Doughty North, Orcas Island	sjs	fringe	2011	2017	5	decline
sjs0635	Watmough Bay, Lopez Island	sjs	fringe	2003	2016	10	decline
sjs0983	Dallas Bank East, Protection Island	sjs	fringe	2009	2017	6	decline

site_code	site_name	region	hab_type	start	end	years sampled	long_term_trend
sjs2646	Eagle Creek, Port Discovery	sjs	fringe	2000	2015	6	decline
sjs2705	Port Angeles Ferry Terminal	sjs	fringe	2009	2015	4	decline
flats73	Salmon Bank, San Juan Island	sjs	flats	2003	2016	7	increase
sjs0001	Strawberry Bay North, Cypress Island	sjs	fringe	2007	2016	6	increase
sjs0176	White Point, San Juan Island	sjs	fringe	2008	2016	7	increase
sjs0829	Joseph Whidbey State Park N, Whidbey	sjs	fringe	2009	2016	6	increase
sjs2622	Lane de Chantel SE, Port Discovery	sjs	fringe	2011	2017	5	increase
sjs2628	Adelma Beach Rd S, Port Discovery	sjs	fringe	2009	2016	8	increase
sjs2652	Thompson Spit, Miller Peninsula	sjs	fringe	2007	2016	6	increase
sjs2775	Pysht River, Juan de Fuca Strait	sjs	fringe	2003	2015	6	increase
sjs2784	5 sites SE of Slip Point, Juan de Fuca Strait	sjs	fringe	2009	2016	6	increase
flats20	Skagit Bay North	swh	flats	2002	2017	16	decline
flats26	Snohomish Delta N, Everett	swh	flats	2005	2016	6	increase
swh0869	Polnell Point West, Oak Harbor	swh	fringe	2007	2016	6	increase
swh0885	Blower's Bluff North, Whidbey	swh	fringe	2006	2016	6	increase
swh0955	West Langley, SE Whidbey	swh	fringe	2005	2016	10	increase
swh0973	Possession, SE Whidbey	swh	fringe	2006	2016	6	increase
swh1575	Camp Diana East, South Camano	swh	fringe	2001	2015	5	increase
swh1593	Bretland, South Camano	swh	fringe	2000	2015	7	increase
swh1625	N of Mission Beach, Tulalip	swh	fringe	2000	2015	7	increase
swh1647	S of Elliot Point Lighthouse, Mukilteo	swh	fringe	2000	2010	5	increase

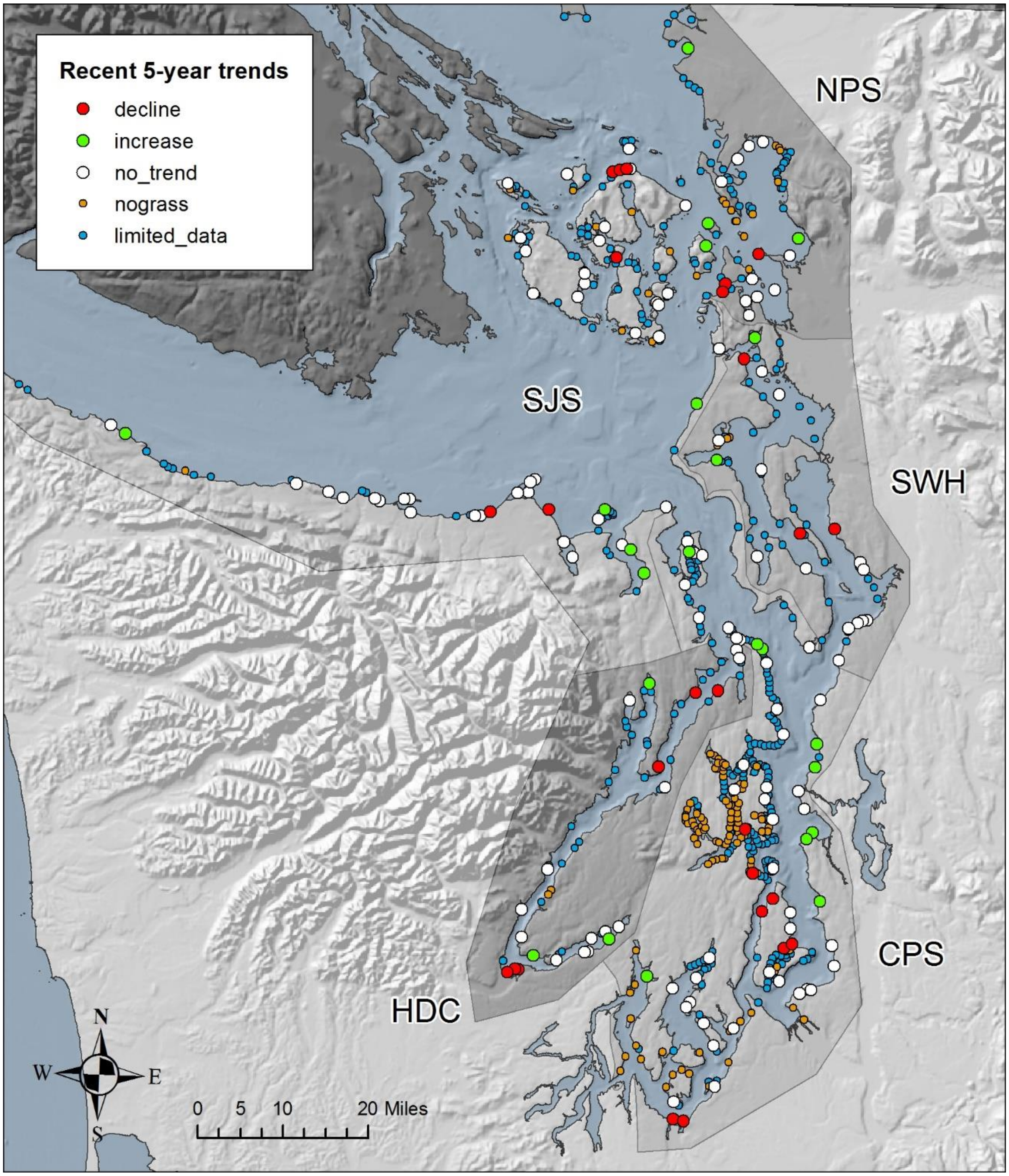


Figure 24: Recent 5-year trends for all sites sampled between 2013 and 2017 by the SVMP.

Table 5: Summary of sites with recent increases or declines.

site_code	site_name	region	hab_type	start	end	years sampled	recent_5_year_trend
cps1035	NE of Point White, Bainbridge	cps	fringe	2005	2016	7	decline
cps1137	Southwest Cove Rd, Vashon	cps	fringe	2011	2017	5	decline
cps1141	NE of Fern Cove, Vashon	cps	fringe	2008	2016	6	decline
cps1160	Portage, Vashon	cps	fringe	2006	2016	7	decline
cps2105	Yukon Harbor, Port Orchard	cps	fringe	2009	2016	6	decline
flats33	Quartermaster Harbor, Vashon	cps	flats	2004	2017	4	decline
flats34	Nisqually Delta West	cps	flats	2007	2017	3	decline
flats35	Nisqually Delta East	cps	flats	2000	2017	13	decline
cps0046	East Indian Island	cps	fringe	2007	2017	3	increase
cps1673	S of Innis Arden Reserve, Shoreline	cps	fringe	2013	2016	4	increase
cps1678	Carkeek Park SW, Greenwood	cps	fringe	2013	2017	3	increase
cps1722	Duwamish Head, Seattle	cps	fringe	2013	2017	5	increase
cps1724	Alki Beach Park East, Seattle	cps	fringe	2013	2017	5	increase
cps1739	Seahurst Park, Burien	cps	fringe	2013	2017	5	increase
cps1967	Sunshine Beach, Vaughn	cps	fringe	2004	2016	10	increase
cps2221	Point No Point Lighthouse South	cps	fringe	2002	2015	8	increase
cps2223	Norwegian Point South, Kingston	cps	fringe	2011	2017	6	increase
hdc2259	Sunset St NE, Poulsbo	hdc	fringe	2014	2017	2	decline
hdc2380	Skokomish Flats East	hdc	fringe	2005	2017	7	decline
hdc2381	Skokomish Flats West	hdc	fringe	2005	2017	7	decline
hdc2383	Indian Hole, Anna's Bay	hdc	fringe	2004	2015	7	decline
hdc2492	NW of Hazel Point, Toandos Peninsula	hdc	fringe	2012	2017	4	decline
hdc2511	South Point, Oak Bay	hdc	fringe	2010	2017	7	decline
flats43	Tarboo Bay	hdc	flats	2000	2015	8	increase
hdc2338	S of Wildberry Lake, Tahuya	hdc	fringe	2000	2015	11	increase
hdc2359	SW Lynch Cove, Belfair	hdc	fringe	2000	2016	12	increase
nps0652	Kelly's Point, Guemes Island	nps	fringe	2009	2017	8	decline
nps1461	Camp Kirby, Samish Island	nps	fringe	2014	2017	2	decline
nps1487	Loverick's, Anacortes	nps	fringe	2008	2016	7	decline
flats03	Birch Bay	nps	flats	2009	2016	6	increase
flats11	Samish Bay N	nps	flats	2001	2017	17	increase
nps0064	W of Boulder Reef, Sinclair Island	nps	fringe	2014	2017	2	increase
core002	Picnic Cove, Shaw Island	sjs	flats	2000	2017	18	decline
core003	Jamestown, Sequim	sjs	flats	2000	2017	18	decline
outf456	Orcas Outfall Study Control 1	sjs	fringe	2013	2017	5	decline
outf457	Orcas Outfall Study Site	sjs	fringe	2013	2017	5	decline
sjs0454	Point Doughty North, Orcas Island	sjs	fringe	2011	2017	5	decline
sjs2688	McDonald Creek, Dungeness	sjs	fringe	2006	2017	3	decline
flats69	Eagle Harbor, Cypress Island	sjs	flats	2010	2017	5	increase
sjs0829	Joseph Whidbey State Park N, Whidbey	sjs	fringe	2009	2016	6	increase
sjs0983	Dallas Bank East, Protection Island	sjs	fringe	2009	2017	6	increase
sjs2622	Lane de Chantel SE, Port Discovery	sjs	fringe	2011	2017	5	increase
sjs2628	Adelma Beach Rd S, Port Discovery	sjs	fringe	2009	2016	8	increase
sjs2781	5 sites NW of Pillar Point, Juan de Fuca Strait	sjs	fringe	2011	2017	5	increase
swh0848	Ben Ure Spit North, Whidbey	swh	fringe	2000	2017	10	decline
swh1574	Camp Diana West, South Camano	swh	fringe	2012	2017	4	decline
swh1615	Sunny Shores N, Tulalip	swh	fringe	2006	2016	6	decline
flats18	Similk Bay	swh	flats	2000	2015	12	increase
swh0901	Long Point East, Coupeville	swh	fringe	2013	2017	3	increase

3.3 Results from the rotating panel design

3.3.1 Change in soundwide seagrass area

Starting in 2015, sites were sampled using a rotating panel design, which repeats 3 independent panels of sites sampled in 2004, 2009 and 2014 (Figure 1). This allows for more precise estimates of change over time. As of 2017, each panel has been revisited once.

Seagrass area increased significantly in the narrow and wide fringe strata between 2004 and 2015. The change in area was not significantly different from zero for the core, persistent flats and rotational flats (Figure 25). Overall, the soundwide seagrass area estimate was significantly higher in 2015 as compared to 2004. The seagrass area estimate also increased significantly between 2009 and 2016. Here, there was a significant increase for the core, rotational flats and narrow fringe strata. There was no significant difference in seagrass area for any of the strata between 2014 and 2017 (Figure 25).

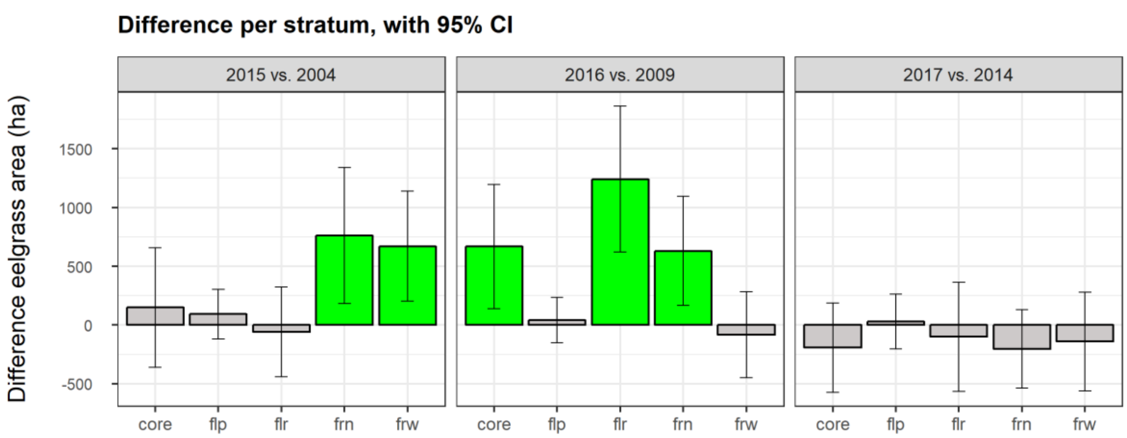


Figure 25: Difference in seagrass area per stratum between pairs of years with the same sample of sites (mean ± SE). The strata are core, persistent flats (flp), rotational flats (flr), narrow fringe (frn) and wide fringe (frw). The change intervals depicted are 11 years (2015 vs 2004), 7 years (2016 vs 2009) and 3 years (2017 vs 2014). Green bars represent a significant increase, grey bars indicate no change over time.

By resampling the same sites and extrapolating the differences in site area between pairs of sites, we are able to generate a higher precision estimate of change over distinct periods of time. However, these change estimates are still estimated based on a relatively small sample of sites (~80 out of 2467 potential sample sites). This could partly explain why we see different estimates for individual strata when comparing the 2004-2015 and 2009-2016 panel years.

3.3.2 *Change at the site level*

The new rotating panel design allows us to look at trends based on pairwise comparisons between years for individual sites. For the 80 sites sampled in 2009 and 2016, and the 79 sites sampled in 2014 and 2017, we detected trends using T-tests on the difference in vegetated fraction on paired transects between the two sample years, weighted by mean transect length. Sites were classified as increasing, declining or stable based on the results of the weighted T-tests, using an alpha of 0.05. Change estimates were confirmed by visual analysis of the plotted transect data.

3.3.2.1 Change assessment: 2009-2016

In 2016, we resampled all SRS transects in each site sampled in 2009. Out of 80 sites sampled with repeat transects in 2009 and 2016, 12 were classified as declining, 25 as increasing, 26 as stable (no trend detected), and 16 sites had no vegetation present (Figure 26 and Table 6). At one site, sjs2632, seagrass was present, but there was not enough for trend assessment. The results of the T-tests were overruled in four instances, based on visual assessment of the transect data. At one site (cps1035), seagrass disappeared from the sampled transects in 2016. This site was classified as declining. Flats 16 had a p-value of 0.051, but visually there was a clear pattern of decline. This site was classified as declining. Flats20 had a p-value of 0.087, but was labeled as declining because of the distinct decline at the southern part of the site due to the avulsion of the Skagit River. Hdc2284 was labeled as stable because of difficulties in identifying the spatial extent of *Zostera marina* and *Zostera japonica*. The relatively high number of significant trends in the 2009-2016 panel illustrates that it is easier to detect trends when the same transects are resampled over time, as compared to resampling the sites with new draw simple random transects.

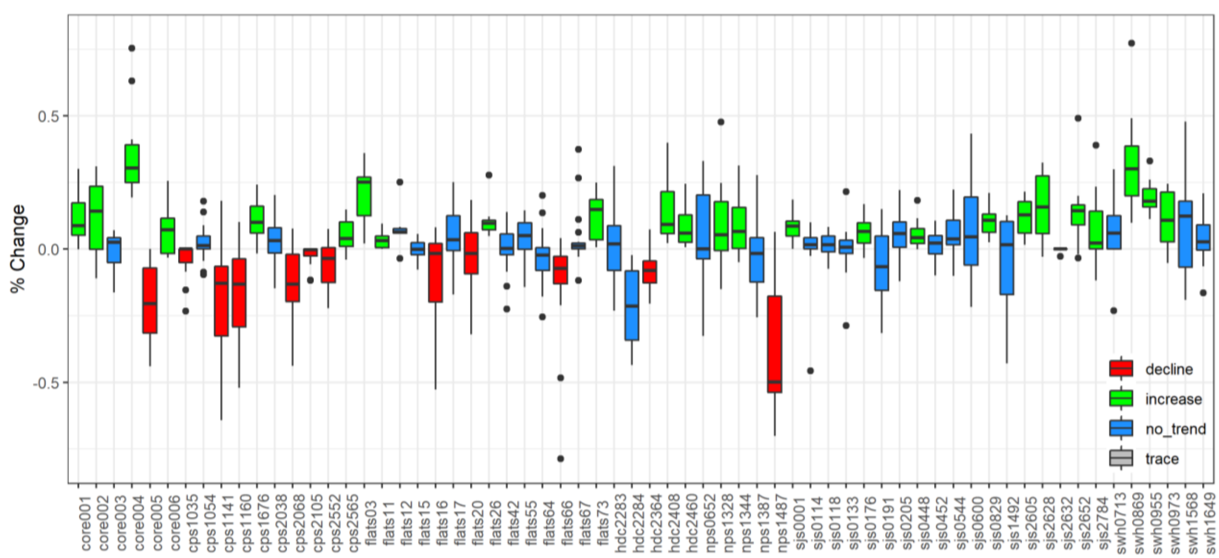


Figure 26: Boxplots of change in vegetation fraction along SRS transects sampled in 2009 and 2016. Sites without native seagrass present are not shown. Sites with significant increases (as result of the weighted paired T-test) are indicated in green, sites with significant declines are indicated in red, stable sites (with non-significant change estimates) are indicated in blue.

Table 6: Change assessment for the 2009-2016 panel (n = 80). Trends are based on paired T-tests of vegetation fraction for repeat transects, weighted by mean transect length (note: one site was considered trace and not assigned a trend).

2009-2016 site trends				
region	decline	increase	no grass	stable
CPS	7	3	9	2
HDC	1	3	1	3
NPS	2	5	1	4
SJS	1	10	3	14
SWH	1	4	2	3
TOTAL	12	25	16	26

3.3.2.2 Change assessment: 2014-2017

In 2017, we resampled all SRS transects in each site sampled in 2014. Out of 79 sites sampled with repeat transects in 2014 and 2017, 15 were classified as declining, 9 as increasing, 42 as stable, and 11 sites had no vegetation present (Figure 27 and Table 7). At two sites, native seagrass was present, but there was not enough for trend assessment. The results of the T-tests were overruled in four instances. At one site (sjs0987) there were some issues with the repeat transects and the sample polygon, so we used an alpha of 0.01 instead of 0.05 to assess if there was a significant trend. As a result, this site was classified as stable. At flats 33 (Inner Quartermaster Harbor), seagrass completely disappeared. This site was classified as declining. At two locations (cps1153 and cps1764) the classification of *Zostera marina* and *Zostera japonica* was inconsistent. These locations were listed as stable.

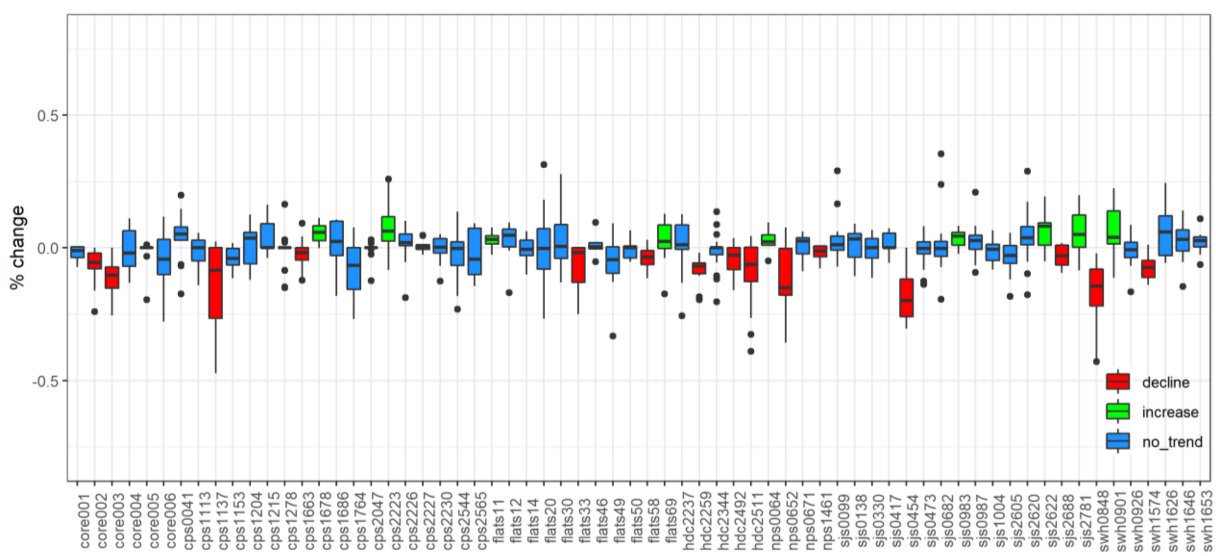


Figure 27: Boxplots of change in vegetation fraction along SRS transects sampled in 2014 and 2017. Sites without native seagrass present are not shown. Sites with significant increases (as result of the weighted paired T-test) are indicated in green, sites with significant declines are indicated in red, stable sites (with non-significant change estimates) are indicated in blue.

The lower number of significant trends as compared to 2009-2016 is probably due to the shorter interval of time between the repeat sampling (3 years as compared to 7 years). The width of the boxplots in Figure 27 is small compared to Figure 26. This suggests that there was less change in seagrass cover along individual tracks between 2017 and 2014 as compared to 2016 and 2009.

Table 7: Change assessment 2014-2017 panel (n = 79). Trends are based on paired T-tests of vegetation fraction for repeat transects, weighted by mean transect length (note: 2 sites were considered trace and not assigned a trend).

2014-2017 site trends				
region	decline	increase	no grass	stable
CPS	3	2	3	18
HDC	3	0	2	3
NPS	2	2	3	4
SJS	5	4	3	12
SWH	2	1	0	5
TOTAL	15	9	11	42

3.3.2.3 Spatial patterns at the regional scale

Figure 28 shows the spatial pattern of change at individual sites sampled as part of the 2009 and 2014 panels. Note that there are some symbols that are overlapping each other as certain sites (core and persistent flat sites and 5 additional sites) are sampled as part of both panels. The 2009-2016 panel comparison (indicated by the diamonds on Figure 28) shows more sites with increases than declines in all regions of greater Puget Sound, except south central Puget Sound. The 2014-2017 comparison (squares on Figure 28) show a different pattern: there are more declines than increases over this period of time. However, the magnitude of these changes is relatively small as compared to the changes between 2009 and 2016 (Figure 26 and Figure 27). The region near Vashon Island stands out as a location with a high number of site level declines. Site core006 at the head of Carr Inlet is labeled as increasing between 2009 and 2016, but this increase is small compared to earlier declines at this location. There is a relatively high number of site level increases between 2009 and 2016 near the San Juan Islands. This is in contrast with the long-term site level declines documented in section 3.2.4 (Figure 23). This is partly due to the differences in sample size and timing of sampling. Certain sites with pronounced declines (Westcott Bay, Swifts Bay, and Watmough Bay) are not part of the 2009 panel, while other sites (Picnic Cove) are variable over time have different change assessments depending on the period in question.

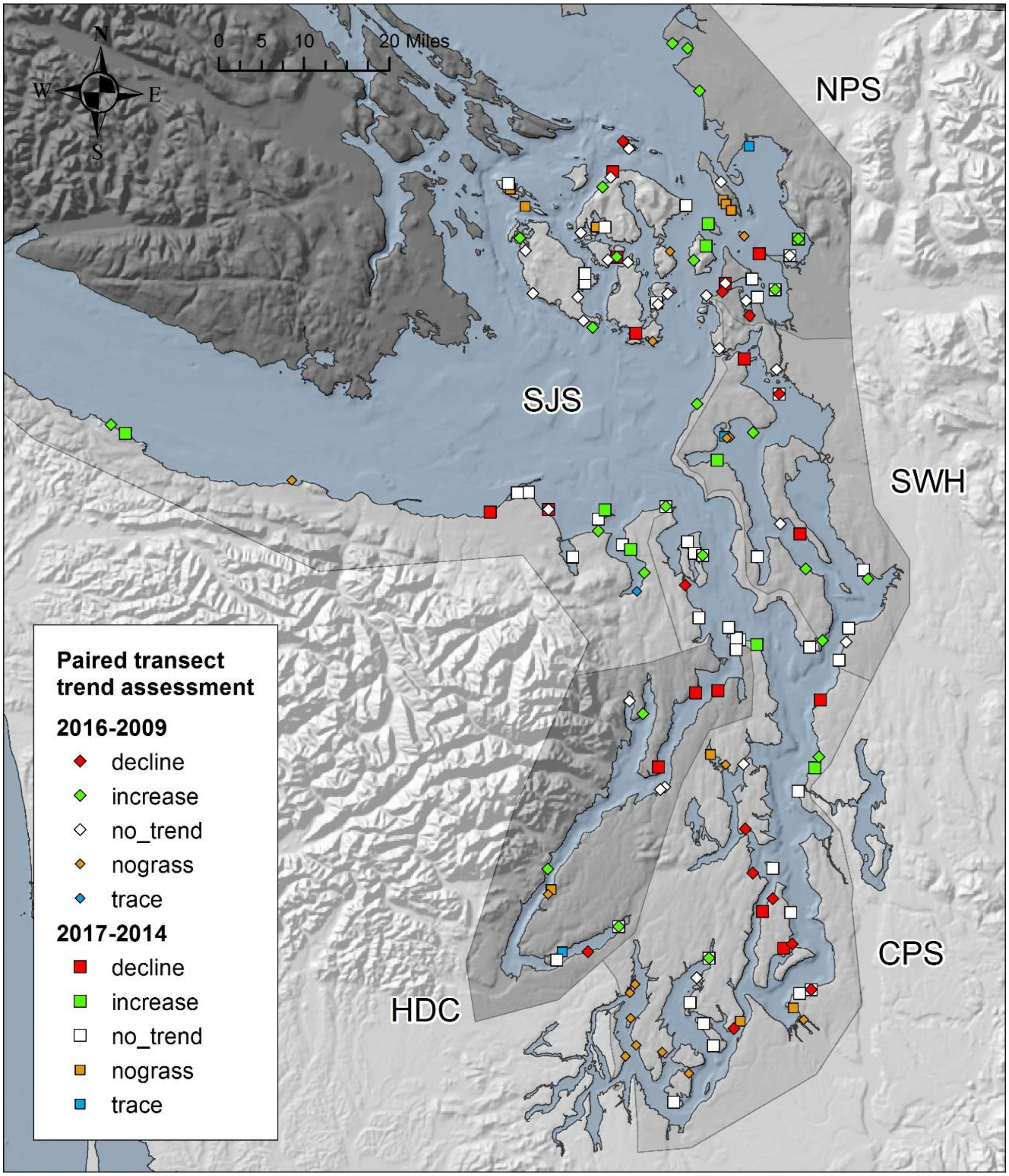


Figure 28: Change assessment based on paired transect comparisons for all sites sampled in 2009-2016 and 2014-2017.

3.3.2.4 Spatial patterns within a site.

The SVMP is designed to assess trends at the site level or higher. However, since the introduction of repeat transect sampling in 2016, we have improved our ability to look at spatial patterns of change within sites. At a number of sites there is a clear lateral pattern of change in the seagrass beds. An example is Skagit Bay N (flats 20), where a recent avulsion has rerouted the flow of the North Fork of the Skagit River, and changed the distribution of eelgrass along the tidal flat (Figure 29). Eelgrass is being lost by the erosion in the southeastern end of the site, but there is some recovery at the northern part of the site where the majority of the river outflow used to be. More commonly, spatial patterns reflect changes in depth distribution within sites. An example is swh0848, where there was a clear decline in the shallow parts of the eelgrass beds between 2014 and 2017 (Figure 30). Changes in depth distribution are explored in more detail in section 3.3.3.

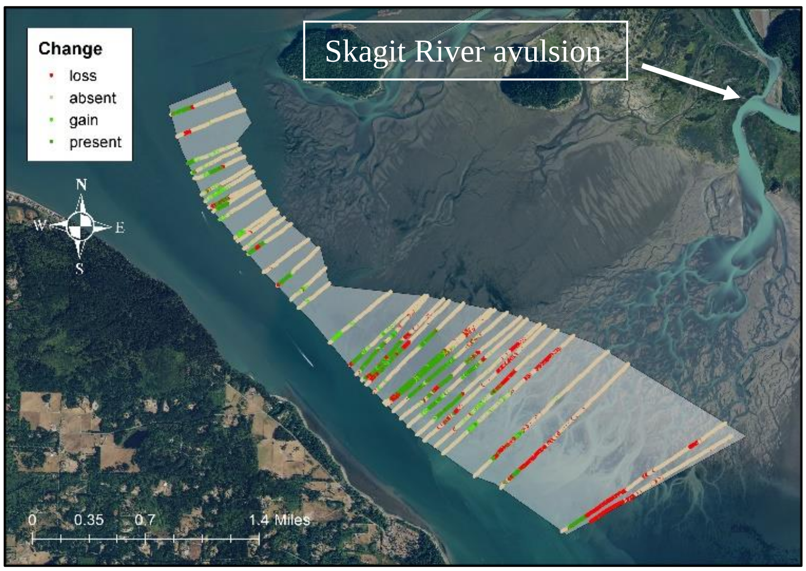


Figure 29: Change in vegetation cover along repeat transects at flats20 (Skagit Bay N). Data are from both the 2009-2016 and the 2014-2017 comparisons.

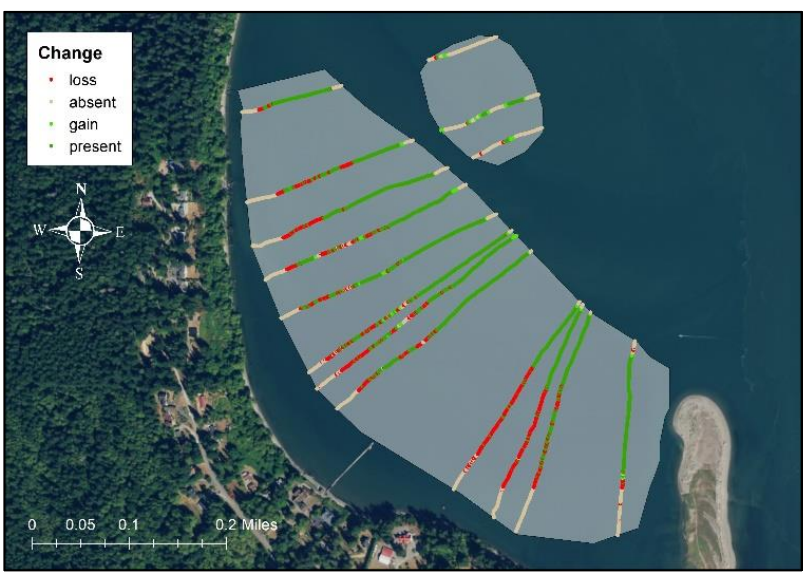


Figure 30: Change in vegetation cover along repeat transects at swh0848. Data are from the 2014-2017 comparison.

3.3.3 Changes in depth distribution

Figure 31 and Figure 32 show boxplots of the percent change in total vegetated fraction in shallow and deep areas of individual sites between 2009 and 2016 and 2014 and 2017, split up per region. Both figures indicate that there is high variability between individual sites. However, some patterns do appear. Changes in vegetated fraction tend to be larger for the 2009-2016 panel. For this panel comparison, there appears to be an increase at the shallow parts of native seagrass beds in northern Puget Sound and the Saratoga-Whidbey Basin, and a general increase in the deeper parts of native seagrass beds in the Hood Canal area (Figure 31). Between 2014 and 2017, native seagrass was relatively stable at depth. However, there appeared to be a small but widespread decline in shallow parts of native seagrass beds in all regions of greater Puget Sound (Figure 32).

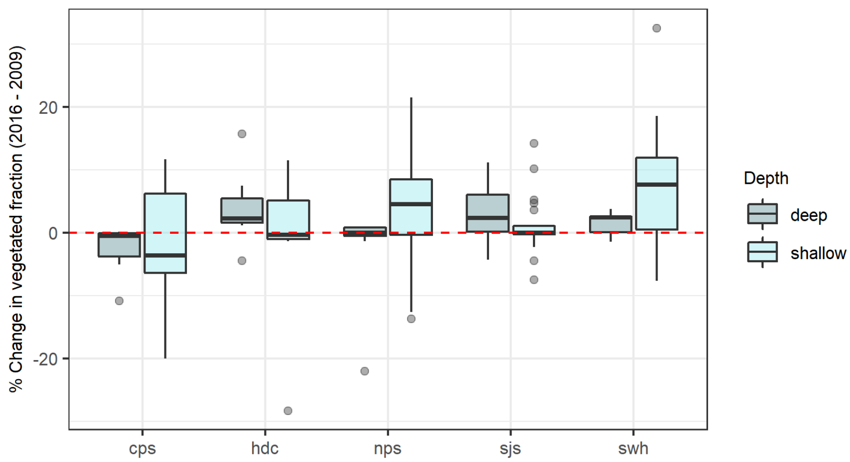


Figure 31: Change in vegetation fraction in shallow and deep areas of native seagrass beds at individual sites between 2009 and 2016, split per region. Values above the red line indicate increases and values below the red line indicate declines. Shallow and deep areas were defined as shallower or deeper than -2m (MLLW).

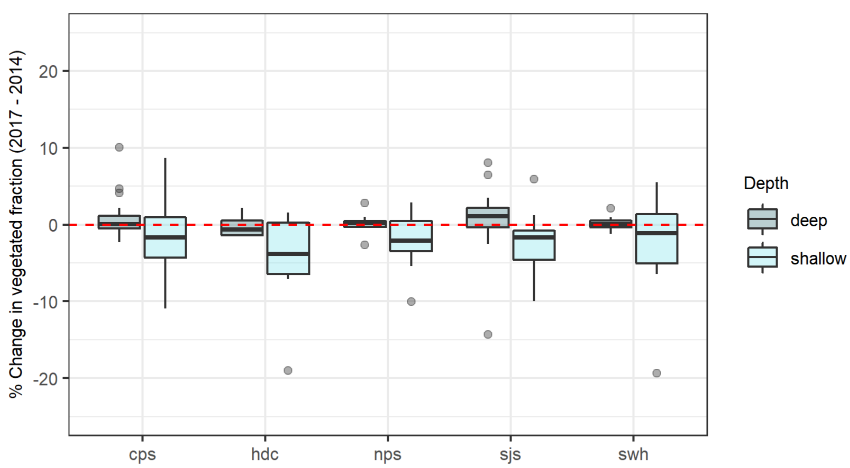


Figure 32: Change in vegetation fraction in shallow and deep areas of native seagrass beds at individual sites between 2014 and 2017, split per region. Values above the red line indicate increases and values below the red line indicate declines. Shallow and deep areas were defined as shallower or deeper than -2m (MLLW).

Figure 34 and Figure 35 show the percent change in native seagrass observations in 0.5m depth bins along paired transects at individual sites sampled in 2009/2016 and 2014/2017[4]. Green bars indicate depth bins with increases, red bars indicate depth bins with declines. The position along the x-axis indicates at which depth these increases/declines occurred. The blue vertical line marks -2m (MLLW). Note that while the x-axis is fixed, the y-axis is different for every site, indicating that levels of change vary among sites.

At a majority of sites in Central Puget Sound, Hood Canal, Northern Puget Sound and the Saratoga-Whidbey Basin, the increases or declines happened between 0 and -4m (MLLW). At sites in the San Juan Islands and the Strait change usually extends to deeper depths. This is probably due to the depth distribution of seagrass in greater Puget Sound (see Figure 15 in section 3.2.2.2).

To compare change at the shallow and deep parts of native seagrass beds among the two panels, we tallied the number of sites with a change of more than 2.5% of the total vegetated fraction in either the shallow or deep parts of the site. Between 2009 and 2016, there were 13 sites with declines and 24 sites with increases in the shallow part of the site. Seven sites experienced declines and 19 sites experienced increases in the deeper parts of the site.

Between 2014 and 2017 there were 26 sites with declines and 7 sites with increases at the shallow edge, while there were 3 sites with declines an 9 sites with increases at the deep part of the site. There is a difference between the results from the change analysis on vegetated fraction and the results from the depth analysis. This illustrates that there are several sites with a change in depth distribution but no corresponding change in seagrass area. In other words, the declines at the shallow edge are compensated by increases in the deeper parts of the seagrass bed. Examples include cps1215, flats46, nps0671, sjs0099, sjs0473, and sjs0682 (Figure 35).

[4] We included an annotated map to identify the location of individual panel sites sampled in 2016 and 2017 (Figure 33)

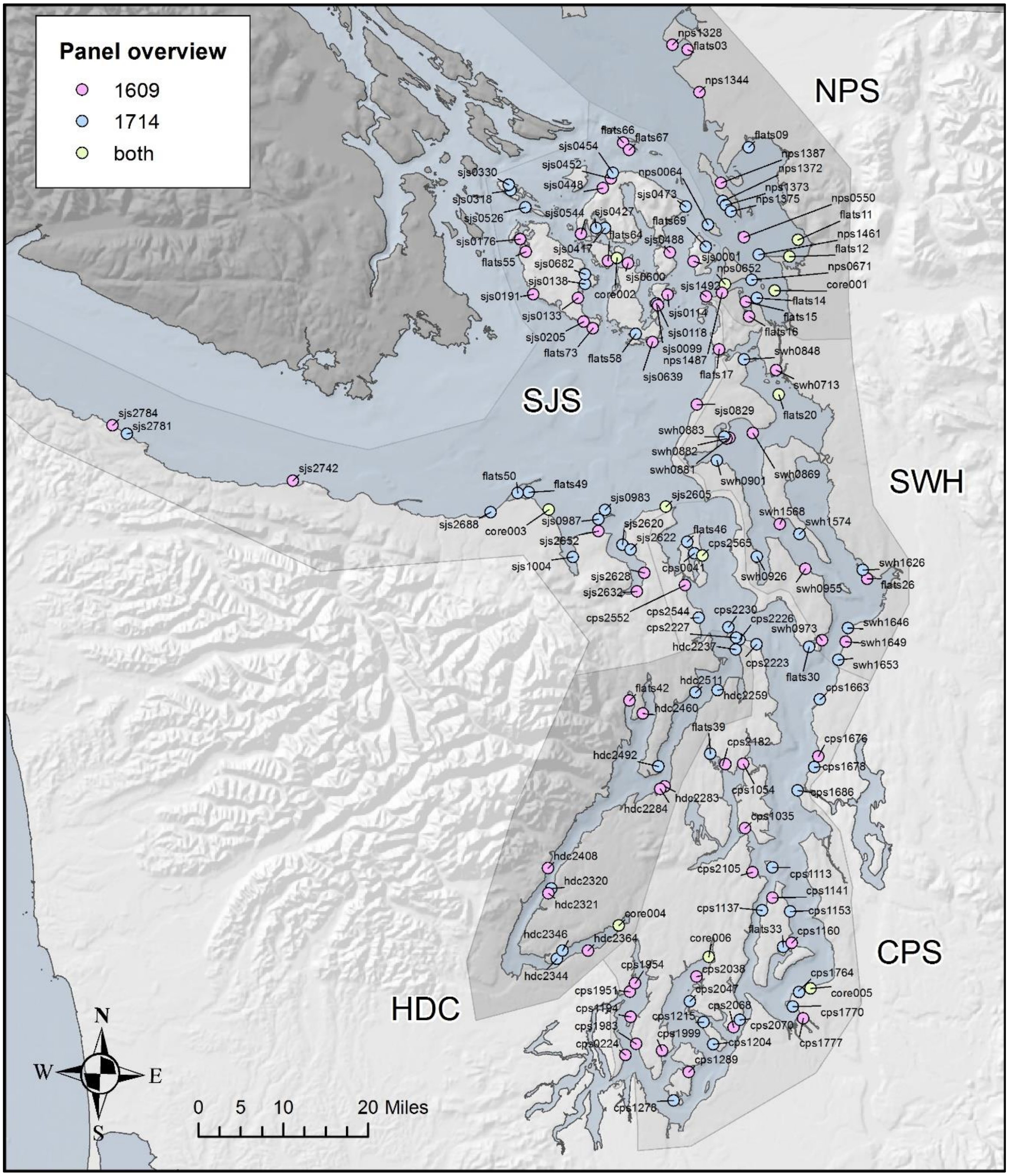


Figure 33: Overview of all panel sites sampled as part of the SVMP in 2009/2016 and 2014/2017

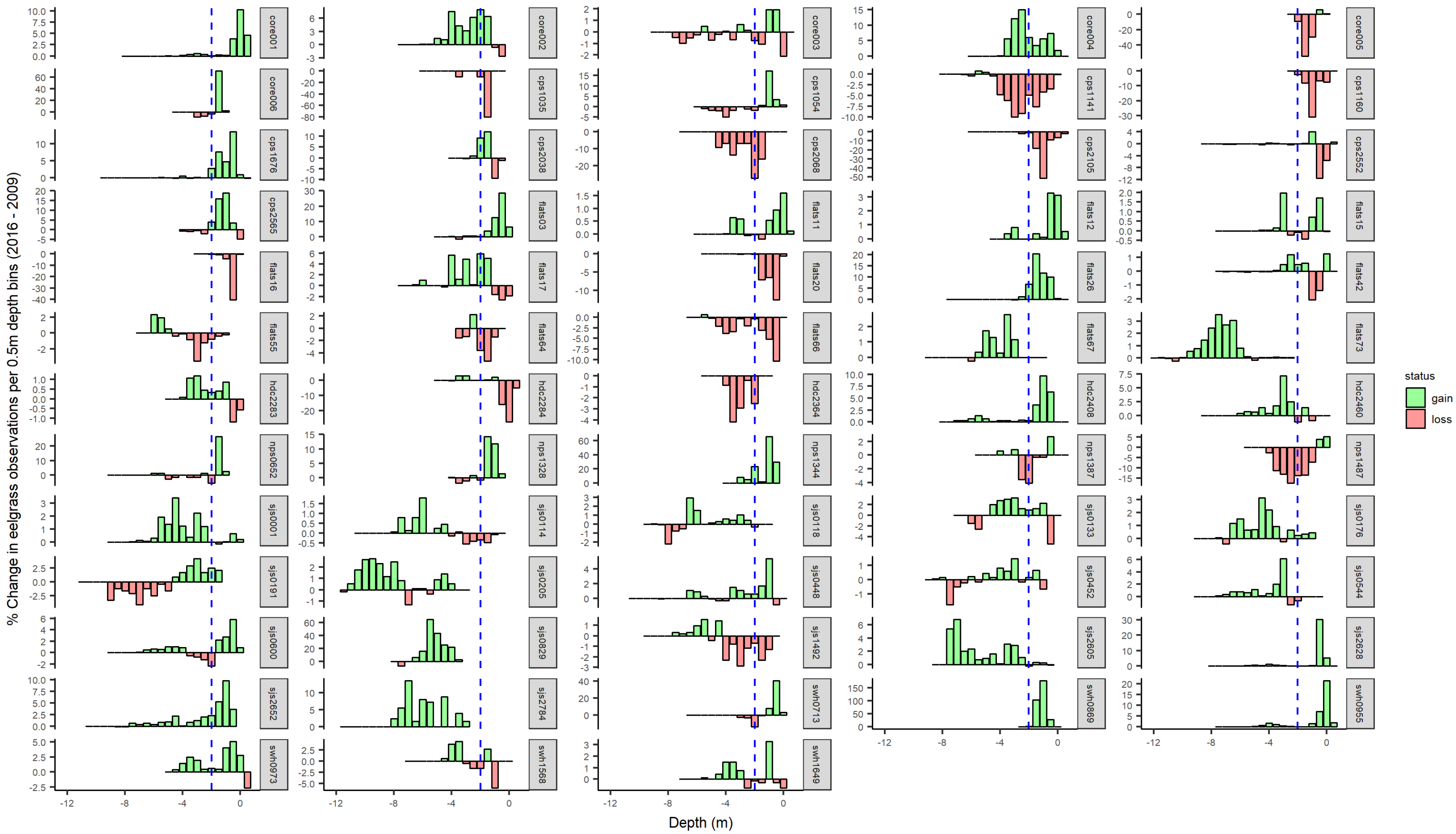


Figure 34: Change in percent native seagrass observations in 0.5m depth bins along paired transects in sites sampled in 2009 and 2016. Green bars indicate depth bins with increases, red bars indicate depth bins with declines.

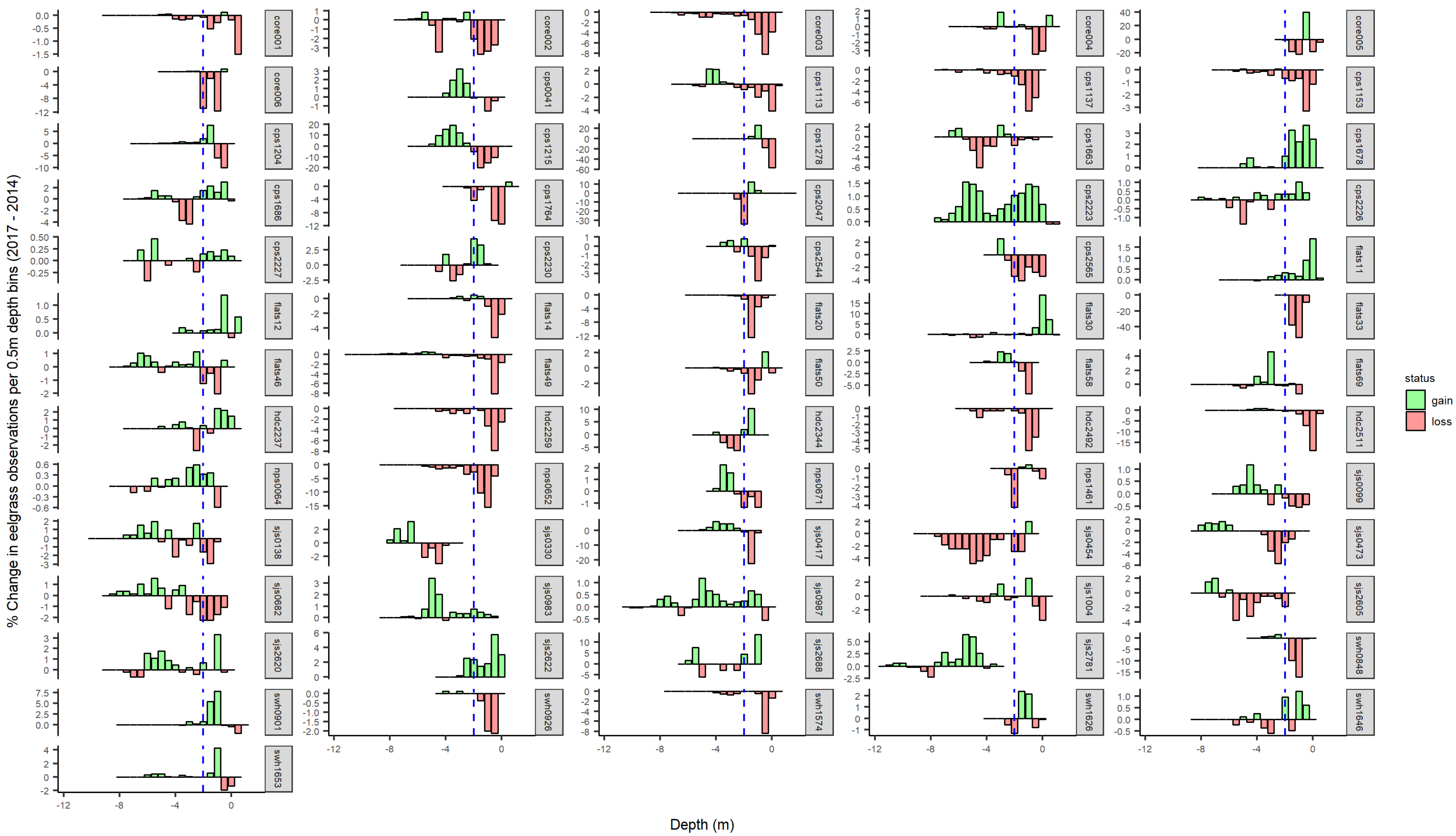


Figure 35: Change in percent native seagrass observations in 0.5m depth bins along paired transects in sites sampled in 2014 and 2017. Green bars indicate depth bins with increases, red bars indicate depth bins with declines.

3.4 STR vs SRS transects

In 2016 and 2017, sites sampled as part of the SVMP soundwide study were sampled with two sets of transects. One set is an exact repeat of the simple random sample of transects in the sample polygon from 2009 or 2014. The other sets consists of stratified random transects. Both sample methods produce similar estimates of seagrass area (Figure 36 A), but there seems to be more variability when native seagrass beds are small. Figure 36 B shows the percent difference between the mean estimates of site seagrass area produced by SRS and STR, relative to the log of site seagrass area estimated by SRS. The relative difference between STR and SRS is highest at sites with less than 1 ha of native seagrass. This is partly due to the fact that SRS transects at sites with small seagrass beds are often targeted to a sub-site sample polygon while STR transects are always targeted to a sample polygon that spans the entire site. As such SRS is more precise at sites where seagrass beds are small.

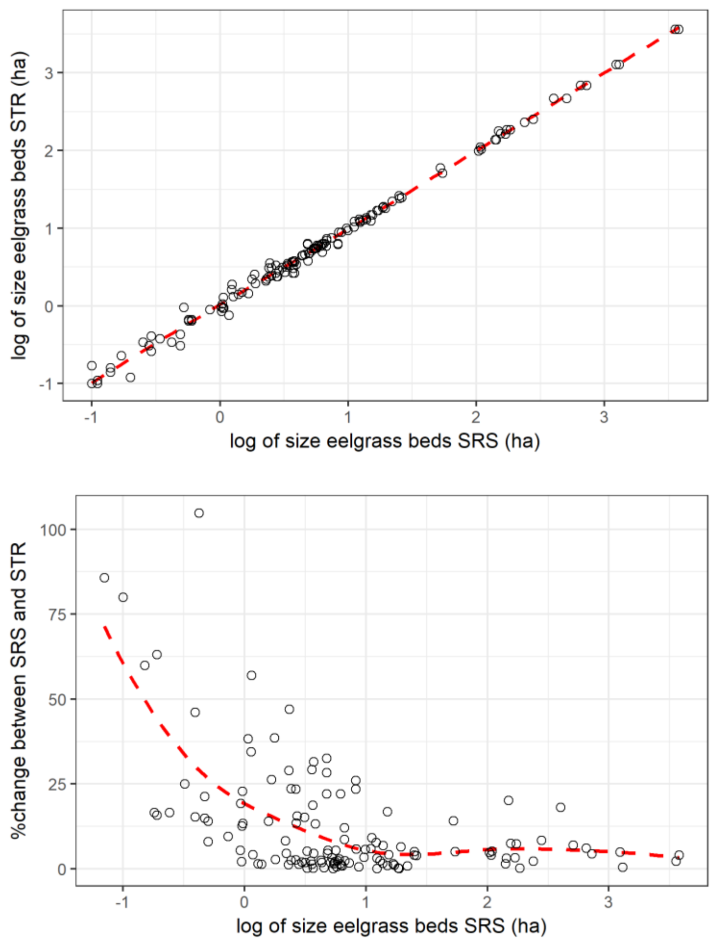


Figure 36: A. estimates of seagrass area based on STR transects vs. estimates of seagrass area based on SRS transects B. % change between SRS and STR estimates vs. log size of seagrass beds (ha) based on SRS transects. Sites without native seagrass were excluded from the analysis.

Despite these small changes, there is little difference between the estimates of soundwide seagrass area calculated with SRS and STR. Figure 37 shows soundwide seagrass area in 2016 and 2017 calculated with both SRS and STR relative to the baseline and the 2020 target of a 20% increase in seagrass area. The 2016 SRS estimate is 24,906 ± 1,914 ha, while the STR estimate is 25,070 ± 1,943 ha. The 2017 SRS estimate is 23,434 ± 2,119 ha, while the STR estimate is 23,210 ± 2,025 ha. The differences between the mean values calculated with the two different methods are an order of magnitude smaller than the standard error around these estimates.

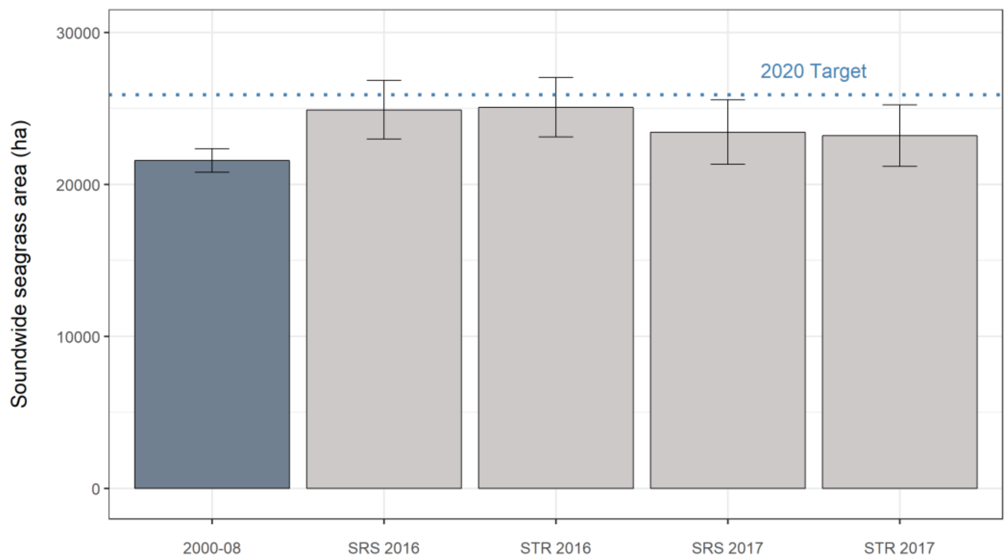


Figure 37: Soundwide seagrass area in 2016 and 2017 calculated based on SRS and STR, relative to the 2000-08 baseline and the 2020 recovery target.

These results highlight some of the strengths and weaknesses of the different sample methods. SRS tends to perform better than STR at smaller sites for estimating site seagrass area. This is not due to the SRS selection per se, but to the differences in the protocols for sample polygon delineation. However, the differences between both methods are not big enough to have a noticeable effect on the soundwide seagrass area estimate. The main advantage of STR is that it spans the entire site, and thus allows for detecting expansion of seagrass beds when using repeat transect analysis. SRS transects are limited to the sample polygon, and may be biased when using repeat transect analysis at sites where small seagrass beds have lateral expansion over time.

4 Discussion

4.1 Importance of long-term monitoring

Seagrasses are an important but vulnerable component of coastal ecosystems. They are sensitive to a wide range of human actions, such as dredging, trawling, and the excessive input of nutrients and organic matter from coastal watersheds. As such they are used as a bio-indicator of ecosystem health – both globally and within Puget Sound (Krause-Jensen et al. 2005, Orth et al. 2006, Mumford 2007). It is often difficult to distinguish the effects of anthropogenic stressors from natural variability. Seagrass beds are influenced by seasonal, inter-annual and long-term oscillations in climate, and by spatial variability in physical and biological processes, such as erosion, sedimentation, grazing and disease (Den Hartog 1987, Duarte 1989, Heck and Valentine 2007, Rasheed and Unsworth 2011). Long-term monitoring can provide insights into inter-annual variability of seagrass beds, and help distinguish natural variability from the effects of human disturbance. Regional monitoring can provide insight in the spatial variability of seagrass beds and the extent of human disturbance.

Greater Puget Sound is a complex system of deep basins, shallow bays and interconnecting channels. It has over 3000 km of shoreline, and a wide variety in potential seagrass habitat. Throughout this area, there are strong gradients in both tidal range, river discharge, and human population density in the surrounding watersheds. The SVMP generates long-term data used to assess the status and trends of native seagrasses in greater Puget Sound. This monitoring program was designed to identify trends in native seagrass area on multiple spatial scales.

4.2 Status and trends of seagrass in greater Puget Sound

4.2.1 Different seagrass populations

Since 2000, the SVMP has monitored seagrass at 652 different sites in greater Puget Sound. Eelgrass (*Zostera marina*) was present at 521 sites, the non-native *Zostera japonica* was present at 178 sites, and surfgrass (*Phyllospadix sp.*) was present at 51 sites.

Our current best estimate is that there is approximately 23,000 ha of native seagrass (predominantly eelgrass) in greater Puget Sound. This number is revised upwards as compared to previous reports (Christiaen et al. 2016), and is based on the most recent 3-year average of soundwide seagrass area (Figure 21).

The majority of native seagrass in greater Puget Sound is found between 0 and -4m (MLLW), but native seagrass has been documented as shallow as 1.4m and as deep as -12.5m (MLLW). Approximately 50% of all native seagrass in greater Puget Sound grows deeper than the Extreme Low Tide (ELT) line[5]. This has implications for the protection of seagrass, since the ELT line forms the boundary between tidelands and bedlands for a large part of Puget Sound. Virtually all bedlands in Washington are owned by the State, while only 29% of Washington's tidelands remain in public ownership (Ivey 2014). This suggests that a large portion of native seagrass is found on State Owned Aquatic Lands, which emphasizes the importance of continued stewardship by DNR.

Zostera marina, the predominant native seagrass, is widespread in greater Puget Sound. It is found in each of the 5 regions of the Sound, but it is absent/scarce in South Puget Sound, Liberty Bay and Dyes Inlet. Eelgrass grows mostly on sandy and muddy substrates. The plants are morphologically plastic: canopy height ranges from less than 40 cm all the way up to 2m, depending on the depth and the location in Puget Sound.

Phyllospadix grows predominantly in rocky substrates, and is mostly found at sites along the Strait of Juan de Fuca, the San Juan Islands, and (to a lesser degree) Admiralty Inlet. For the most part these are locations where *P. scouleri* grows in a narrow band close to shore. At some locations, *P. serrulatus* appears to grow interspersed with *Zostera marina* in a mixed cobble-sand environment. This is somewhat unusual as *Phyllospadix* is traditionally considered to only grow on hard substrates. Since our data is mostly based on towed underwater video, we were not able to discern the nature of belowground attachment of *P. serrulatus* at these sites. However, there is evidence that *P. serrulatus* is able to grow on soft substrates, mixed with *Z. marina*, in other parts of the Pacific Northwest (Tiffany Stephens, personal communication).

The non-native *Zostera japonica* is common in all regions of greater Puget Sound except the San Juan Islands and the Strait. We detected this species at nearly 30% of all sites sampled as part of the SVMP. This is likely an underestimation of the actual distribution. *Z. japonica* grows relatively high up in the intertidal, and is sometimes out of reach of our sample vessel. The vast majority of sites with *Z. japonica* also contained *Z. marina*. This suggests that both species have similar requirements in terms of habitat and substrate. Despite this finding, there was little overlap in the vertical distribution of both species in greater Puget Sound. There is little evidence of direct competition between *Z. japonica* and the native *Z. marina* in the Pacific Northwest (Shafer 2014). The intertidal zonation patterns may be driven by adaptation to different thermal regimes: increased duration of exposure to cold water temperatures appears to limit the deep edge of *Z. japonica* beds to the mid-intertidal (Kaldy et al. 2015).

[5] For the purpose of designating ownership boundaries, the federal government defined the Extreme Low Tide line (ELT) as the line below which it might be reasonably expected that the tide would not ebb. In the Puget Sound area of Washington State this line is estimated by the federal government to be a point in elevation 4.5 ± 0.5 feet below the datum plane of MLLW (Ivey 2014).

4.2.2 Spatial patterns in seagrass distribution

Native seagrass has a distinct spatial distribution in greater Puget Sound. Approximately 50% of seagrass grows on tidal flats, and the remaining 50% grows on fringe sites along the shoreline. In Northern Puget Sound and the Saratoga Whidbey Basin the majority of native seagrass grows on tidal flats, while in Central Puget Sound, Hood Canal and the San Juan Islands and the Strait, the majority of native seagrass grows on fringe sites. The size of individual seagrass beds is mostly driven by the amount of available habitat, as indicated by the linear relationship between vegetated area and site area (Figure 13).

There is also a clear regional pattern in the depth distribution of native seagrass beds. Seagrass depth range is largest at sites near Admiralty Inlet, the San Juan Islands and Strait, and smallest in South Puget Sound, the Saratoga Whidbey Basin and Bellingham Bay. A similar gradient exists at from the mouth to the head of enclosed embayments such as Kilisut Harbor, Quartermaster Harbor and Port Orchard. These patterns are likely driven by a combination of different factors, including regional changes in water clarity, a north to south gradient in tidal range, and localized water quality impairments.

Seagrasses have high light requirements because they support a large biomass of roots and rhizomes in relation to their size (Hemminga 1998, Lee et al. 2007). The maximum depth at which they grow is determined by the amount of light that filters through the water column. The limited depth range at sites in Bellingham Bay and the Saratoga Whidbey Basin is likely influenced by turbidity from the Nooksack, Skagit and Stillaguamish rivers.

Tidal range[6] varies from 2m at the mouth of the Strait, to 4.4m in South Puget Sound. The limited seagrass depth range at sites with high tidal range could be related to longer exposure to air at the shallow edge during low tides, which increases the risk of desiccation of leaves, and light limitation at the deep edge during high tides (Koch and Beer 1996).

Recent results from the Department of Ecology's Nutrient Source Reduction Project show that nutrients from anthropogenic sources exacerbate low DO in shallow inlets and bays in South Central Puget Sound, including Quartermaster Harbor (Ahmed et al. 2019). These locations are particularly sensitive to the effects of nutrient over enrichment, because they have lower flushing compared to more open marine waters (Ahmed et al. 2017). Seagrass depth limits are often impacted by nutrient over-enrichment, because of the increased occurrence and duration of harmful algae blooms, and the growth and abundance of green macroalgae (Krause-Jensen et al. 2008, Teichberg et al. 2010). These algae reduce the light available for seagrass, which often leads to increased mortality at the deep edge of the bed.

4.2.3 Trends in soundwide seagrass area

Both annual soundwide seagrass area estimates and the individual site-level trends indicate that seagrass area has been relatively stable in greater Puget Sound between 2000 and 2017. This is consistent with a long-term study on eelgrass in the herring spawn areas in Puget Sound (Shelton et al. 2016). The annual estimates of soundwide seagrass area were 24,906 +/- 1914 ha in 2016 and 23,434 +/- 2119 ha in 2017. The 2017 area estimate is slightly lower than the 2016 estimate, but given the uncertainty around the annual

[6] Calculated as the difference between MHHW and MLLW, using VDATUM - NOAA

estimates it is not possible to interpret if small increases or declines in the estimate represent an actual increase/decline in soundwide seagrass area in greater Puget Sound.

As was reported in a previous SVMP report (Christiaen et al. 2016), annual estimates of soundwide seagrass area are sensitive to certain aspects of the previous SVMP sample design. Every year 20% of all sites were rotated out of the sample pool, and were replaced by new randomly selected sites. As a consequence, the dataset from 2000 to 2014 consists of random sites that are studied for a 5 year period. The 20% rotation in site selection introduced a number of problems for estimating trends in soundwide seagrass area (Dowty 2018). Site rotation has an effect on trend estimates because the five year period gives relatively large or small sites a disproportionate influence on the trend line, sharply increasing variability in trend estimates. The 3 panel design, introduced in 2015, improves the capability to detect trends in soundwide seagrass area, at the cost of limiting the number of new sites that contribute to the soundwide estimate. The 3-year soundwide average for 2015-2017 is 23,142+/- 1115 ha. This value is below the PSP target of a 20% increase in soundwide seagrass area by 2020.

The new design also allows us to do a more precise change detection between individual pairs of years. This analysis is based on extrapolating pairwise differences in site seagrass area (and associated uncertainty), similar to the soundwide seagrass area calculations. The results of this analysis suggests that soundwide seagrass area slightly increased between 2004 and 2015, and between 2009 and 2016. There was no difference in soundwide seagrass area between 2014 and 2017. While the results of this analysis are suggestive, increases between 2 pairs of years do not necessarily imply a long term trend. These results could be caused by inter-annual variability in environmental conditions. In Puget Sound, the residence times in the upper 30m of the water column vary significantly from year to year (Ahmed et al. 2019). This promotes inter-annual variability in nutrient cycling and primary productivity in the Sound, which could lead to inter-annual variability in seagrass cover. More data is needed before we can make inferences about any potential trends in soundwide seagrass area over time.

4.2.4 Site level trends in seagrass area

Out of the 652 sites sampled between 2000 and 2017, there were 524 sites with native seagrass. Out of these sites, there were 276 sites with sufficient data to assess long-term trends and 164 sites with enough data to assess recent 5-year trends. At both timescales, the majority of sites appear stable. On the long term, sites with increases outnumber sites with declines. In recent years, there is no difference between the number of increases and declines. A statistically rigorous assessment of change in vegetation fraction between 2009-2016 and 2014-2017 confirms these patterns. Between 2009 and 2016, sites with increases outnumbered sites with declines, but between 2014 and 2017 there were more declines than increases. These data confirm the patterns at the soundwide scale: overall, native seagrasses have been stable over the last 18 years in greater Puget Sound.

There is an interesting spatial pattern in sites with long-term increases and declines. Sites with increases are mainly located in the Saratoga Whidbey Basin and the northern part of Central Puget Sound. Sites with long-term declines were mostly clustered near the San Juan Islands and near Vashon Island. Native seagrass beds at the head of bays and inlets seem particularly vulnerable to declines (examples include Westcott Bay, Swifts Bay, the southern edge of Fidalgo Bay, Port Orchard, Quartermaster Harbor, and the heads of Carr and Case Inlets). For the majority of sites the reasons for increases/declines remain unclear. However, we have identified potential causes for a number of site level declines. The seagrass beds in Skagit Bay N (flats20) are likely declining because of erosion, caused by the redirected flow of the N fork of the Skagit River. The recent declines at the Nisqually river delta are likely due to a winter storm. Some sites with declines coincide with locations where recent studies indicated a high prevalence of eelgrass wasting disease such as Picnic Cove and NE of Fern Cove (Graham et al. 2018, Eisenlord et al. 2018). Long-term declines in Quartermaster Harbor and at sites at the head of Carr Inlet and Case inlet suggest that water quality impairments may impact seagrass at some locations in greater Puget Sound. Two sites on Orcas Island experienced a marked decline in native seagrass cover after a sewage outfall was relocated closer to shore. In Yukon Harbor, declines in an already sparse seagrass bed are likely due to a thick layer of ulvoid macro algae covering the seagrass bed.

4.2.5 Site level trends in seagrass depth distribution

In 2015 and 2016 the temperature of the water column in different areas of greater Puget Sound was much warmer than the long-term average, due to local atmospheric heating and a mass of water that entered Puget Sound through the Strait of Juan de Fuca, also called 'the blob' (PSEMP Marine Waters Workgroup, 2016 and 2017). In 2015 many locations experienced water column temperature anomalies in excess of 2°C, with the highest values recorded in lower Hood Canal (7°C warmer than usual). In 2016, temperatures were 0.5 to 1°C warmer than normal for most of the year. Warmer temperatures can increase the respiratory burden of seagrasses, increasing their light requirements (Marsh et al. 1986, Lee et al. 2007). This can lead to lower growth rates in light limited environments, such as the deep edge of seagrass beds, nutrient rich areas with high phytoplankton biomass, or turbid river deltas.

Between 2014 and 2017, the majority of native seagrass beds were relatively stable at the deep edge, indicating that the widespread temperature increase did not have a major direct impact on the health of the plants. However, there was a small but widespread decline near the shallow edge of native seagrass beds throughout the Sound. One hypothesis is that these declines were caused by desiccation at low tides, as both 2015 and 2016 were characterized by high air temperatures and low cloud cover between April and September (PSEMP Marine Waters Workgroup, 2016 and 2017). Another potential driver is high amounts of green macro algae in the intertidal. Eyes over Puget Sound detected large mats of drift algae throughout the Sound during the summer of 2015 and 2016 (EOPS 15-03-080 and 16-03-079). High abundance of macro-algae has been associated with declines in density, and could lead to local declines in seagrass cover (Nelson and Lee 2001, Nelson and Sullivan 2018, Bittick et al. 2018).

4.3 Conclusions

- Soundwide seagrass area has remained relatively stable since 2000. This is reassuring and sets Puget Sound apart from many other developed areas, where substantial system-wide declines are ongoing.
- There is some evidence for a slight increase in soundwide seagrass area based on a new analysis that compares individual years sampled with the same panel of sites.
- At this point in time, it seems unlikely that the PSP goal of 20% increase in seagrass area by 2020 will be met. Stressors that affect seagrass in Puget Sound will likely need to be reduced to see significant soundwide gains in seagrass area, depth distribution and overall health.
- Seagrass beds have different characteristics depending on where they grow in greater Puget Sound, and are likely exposed to different stressors depending on their location.
- While the majority of sites appear stable, the spatial pattern in site level declines suggests that seagrass is more susceptible to declines in certain areas of greater Puget Sound.
- We have documented several declines at locations with known or suspected water quality impairments. Locations of concern include the heads of Case and Carr Inlet, inner Quartermaster Harbor, and sites near a shallow outfall on Orcas Island.
- Between 2014 and 2017 there was a small but widespread decline in shallow portions of native seagrass beds throughout greater Puget Sound. Given the spatial scale of these declines, it is likely that they are related to the unusual environmental conditions observed in 2015 and 2016 throughout greater Puget Sound.

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6 Appendix 1:

Table 8: site area estimates and associated standard error for all sites sampled as part of the soundwide estimate in 2016 and 2017. All sites with seagrass have been sampled with SRS repeat transects. All sites except the core and persistent flats in 2017 have an STR sample. Area estimates are native seagrass (no *Z. japonica*).

site_code	*year*	*sample selection*	*transects sampled*	*seagrass area (ha)*	*standard error (ha)*
core001	2016	SRS	11	3791.66	132.55
core001	2016	STR	10	3635.89	163.17
core002	2016	SRS	14	3.26	0.25
core002	2016	STR	10	3.25	0.32
core003	2016	SRS	11	508.06	57.27
core003	2016	STR	12	472.26	48.83
core004	2016	SRS	14	184.26	9.01
core004	2016	STR	15	184.81	9.96
core005	2016	SRS	15	0.15	0.1
core005	2016	STR	20	0.24	0.18
core006	2016	SRS	15	2.31	0.49
core006	2016	STR	15	2.98	0.47
cps0224	2016	STR	0	0	0
cps1035	2016	SRS	12	0	0
cps1035	2016	STR	10	0	0
cps1054	2016	SRS	13	0.95	0.12
cps1054	2016	STR	19	0.83	0.25
cps1141	2016	SRS	16	2.34	0.79
cps1141	2016	STR	15	3.44	0.83
cps1160	2016	SRS	20	1.17	0.23
cps1160	2016	STR	15	1.22	0.29
cps1194	2016	STR	0	0	0
cps1289	2016	STR	0	0	0
cps1676	2016	SRS	14	6.66	0.41
cps1676	2016	STR	10	7.24	0.51
cps1777	2016	STR	0	0	0
cps1951	2016	STR	0	0	0
cps1954	2016	STR	0	0	0
cps1983	2016	STR	10	0	0
cps1999	2016	STR	0	0	0
cps2038	2016	SRS	15	2.17	0.37
cps2038	2016	STR	15	1.99	0.53
cps2068	2016	SRS	10	0.01	0.01
cps2068	2016	STR	20	0	0
cps2105	2016	SRS	12	0.07	0.04
cps2105	2016	STR	20	0.13	0.06
cps2182	2016	STR	0	0	0

site_code	year	sample selection	transects sampled	seagrass area (ha)	standard error (ha)
cps2552	2016	SRS	13	8.31	0.76
cps2552	2016	STR	15	8.8	0.72
cps2565	2016	SRS	15	3.71	0.77
cps2565	2016	STR	14	3.54	0.85
flats03	2016	SRS	12	168.75	12.25
flats03	2016	STR	15	163.07	11.51
flats11	2016	SRS	9	1298.41	56.11
flats11	2016	STR	10	1291.56	41.2
flats12	2016	SRS	11	650.91	35.26
flats12	2016	STR	11	690.64	40.53
flats15	2016	SRS	15	154.78	14.8
flats15	2016	STR	13	166.35	14.25
flats16	2016	SRS	12	14.92	3.65
flats16	2016	STR	12	12.41	2.81
flats17	2016	SRS	22	2.66	0.38
flats17	2016	STR	20	2.3	0.52
flats20	2016	SRS	18	140.11	24.23
flats20	2016	STR	20	137.99	21.34
flats26	2016	SRS	11	148.98	31.02
flats26	2016	STR	10	179.11	37.81
flats42	2016	SRS	13	109.22	4.82
flats42	2016	STR	15	103.52	6.62
flats55	2016	SRS	19	4.75	0.6
flats55	2016	STR	20	3.7	0.56
flats64	2016	SRS	17	1.29	0.12
flats64	2016	STR	15	1.31	0.17
flats66	2016	SRS	20	3.63	0.6
flats66	2016	STR	15	2.95	0.69
flats67	2016	SRS	21	7.28	1.24
flats67	2016	STR	14	7.41	1.93
flats73	2016	SRS	12	237.45	14.31
flats73	2016	STR	12	231.88	14.02
hdc2283	2016	SRS	14	13	0.4
hdc2283	2016	STR	15	12.69	0.48
hdc2284	2016	SRS	14	5.63	0.45
hdc2284	2016	STR	15	5.94	0.44
hdc2321	2016	STR	0	0	0
hdc2364	2016	SRS	7	0.42	0.08
hdc2364	2016	STR	19	0.86	0.35
hdc2408	2016	SRS	11	6.35	0.27
hdc2408	2016	STR	11	6.29	0.31
hdc2460	2016	SRS	12	5.38	0.2
hdc2460	2016	STR	10	5.46	0.35
nps0550	2016	STR	0	0	0
nps0652	2016	SRS	11	0.5	0.12
nps0652	2016	STR	10	0.54	0.12
nps1328	2016	SRS	15	2.29	0.32
nps1328	2016	STR	15	2.26	0.37
nps1344	2016	SRS	14	1.07	0.2
nps1344	2016	STR	15	0.66	0.17
nps1387	2016	SRS	11	3.53	0.22
nps1387	2016	STR	15	3.61	0.17
nps1487	2016	SRS	11	0.94	0.21
nps1487	2016	STR	10	0.96	0.24
sjs0001	2016	SRS	14	12.26	0.4
sjs0001	2016	STR	10	11.87	0.9

site_code	*year*	*sample selection*	*transects sampled*	*seagrass area (ha)*	*standard error (ha)*
sjs0114	2016	SRS	16	11	0.57
sjs0114	2016	STR	10	10.34	0.63
sjs0118	2016	SRS	13	24.9	1.96
sjs0118	2016	STR	10	26.17	2.04
sjs0133	2016	SRS	16	1.76	0.25
sjs0133	2016	STR	15	2.44	0.36
sjs0176	2016	SRS	11	5.21	0.39
sjs0176	2016	STR	10	5.38	0.68
sjs0191	2016	SRS	11	0.39	0.05
sjs0191	2016	STR	8	0.33	0.2
sjs0205	2016	SRS	11	12.3	0.67
sjs0205	2016	STR	9	12.29	0.73
sjs0448	2016	SRS	15	5.5	0.25
sjs0448	2016	STR	14	5.41	0.26
sjs0452	2016	SRS	13	12.1	0.76
sjs0452	2016	STR	10	13.05	1.06
sjs0488	2016	STR	0	0	0
sjs0544	2016	SRS	16	2.2	0.14
sjs0544	2016	STR	15	2.1	0.19
sjs0600	2016	SRS	15	3.15	0.34
sjs0600	2016	STR	15	3.09	0.56
sjs0639	2016	STR	0	0	0
sjs0829	2016	SRS	12	1.57	0.25
sjs0829	2016	STR	15	1.35	0.23
sjs1492	2016	SRS	14	11.1	1.52
sjs1492	2016	STR	12	12.12	1.88
sjs2605	2016	SRS	11	8.19	0.66
sjs2605	2016	STR	10	6.26	1.09
sjs2628	2016	SRS	11	4.25	0.24
sjs2628	2016	STR	10	4.36	0.3
sjs2632	2016	SRS	11	0	0
sjs2632	2016	STR	10	0.07	0.07
sjs2652	2016	SRS	15	6.11	0.5
sjs2652	2016	STR	15	6.2	0.47
sjs2742	2016	STR	10	0.04	0.04
sjs2784	2016	SRS	15	1.13	0.22
sjs2784	2016	STR	20	1.52	0.24
swh0713	2016	SRS	15	0.93	0.11
swh0713	2016	STR	15	0.75	0.29
swh0869	2016	SRS	11	0.19	0.03
swh0869	2016	STR	10	0.31	0.27
swh0881	2016	STR	0	0	0
swh0882	2016	STR	0	0	0
swh0955	2016	SRS	11	13.71	0.36
swh0955	2016	STR	10	13.48	0.35
swh0973	2016	SRS	11	15.39	1.57
swh0973	2016	STR	12	14.75	1.35
swh1568	2016	SRS	16	0.18	0.02
swh1568	2016	STR	15	0.21	0.12
swh1649	2016	SRS	11	5.73	0.22
swh1649	2016	STR	10	5.77	0.22
core001	2017	SRS	11	3552.9	137.42
core002	2017	SRS	15	2.68	0.29
core003	2017	SRS	11	399.82	33.59
core004	2017	SRS	19	172.03	18.3
core005	2017	SRS	11	0.32	0.21

site_code	year	sample selection	transects sampled	seagrass area (ha)	standard error (ha)
core006	2017	SRS	15	2.41	0.5
cps0041	2017	SRS	14	5.55	0.38
cps0041	2017	STR	12	5.43	0.44
cps1113	2017	SRS	11	4.87	0.21
cps1113	2017	STR	10	4.6	0.35
cps1137	2017	SRS	17	3.83	0.4
cps1137	2017	STR	14	3.31	0.51
cps1153	2017	SRS	14	6	0.47
cps1153	2017	STR	11	5.82	0.53
cps1204	2017	SRS	16	2.41	0.26
cps1204	2017	STR	13	2.35	0.32
cps1215	2017	SRS	13	0.19	0.08
cps1215	2017	STR	20	0.16	0.11
cps1278	2017	SRS	15	0.04	0.02
cps1278	2017	STR	15	0.06	0.04
cps1663	2017	SRS	18	6.62	0.6
cps1663	2017	STR	15	5.82	0.69
cps1678	2017	SRS	11	13.75	0.48
cps1678	2017	STR	10	12.81	0.98
cps1686	2017	SRS	12	5.81	0.52
cps1686	2017	STR	10	5.95	0.54
cps1764	2017	SRS	13	4.03	0.46
cps1764	2017	STR	10	3.94	0.53
cps1770	2017	STR	0	0	0
cps2047	2017	SRS	20	0.1	0.05
cps2047	2017	STR	15	0.02	0.02
cps2070	2017	STR	0	0	0
cps2223	2017	SRS	14	6.67	0.38
cps2223	2017	STR	11	6.83	0.52
cps2226	2017	SRS	11	9.88	0.73
cps2226	2017	STR	11	9.31	0.88
cps2227	2017	SRS	11	18.45	0.66
cps2227	2017	STR	12	18.41	0.6
cps2230	2017	SRS	14	0.92	0.21
cps2230	2017	STR	15	0.87	0.36
cps2544	2017	SRS	20	6.18	0.46
cps2544	2017	STR	29	4.81	1.25
cps2565	2017	SRS	13	3.59	0.83
cps2565	2017	STR	12	2.54	0.76
flats09	2017	SRS	10	0.24	0.08
flats09	2017	STR	11	0.28	0.09
flats11	2017	SRS	9	1230.95	68.15
flats12	2017	SRS	11	734.72	35.97
flats14	2017	SRS	14	277.79	20.4
flats14	2017	STR	19	254.21	23.16
flats20	2017	SRS	19	142.6	27.33
flats30	2017	SRS	15	106.78	16.21
flats30	2017	STR	14	111.19	22.6
flats33	2017	SRS	0	0	0
flats33	2017	STR	0	0	0
flats39	2017	STR	0	0	0
flats46	2017	SRS	11	54.2	10
flats46	2017	STR	17	51.42	8.54
flats49	2017	SRS	17	103.6	11.13
flats49	2017	STR	15	98.53	12.02
flats50	2017	SRS	14	52.21	17.06

site_code	year	sample selection	transects sampled	seagrass area (ha)	standard error (ha)
flats50	2017	STR	13	59.64	17.96
flats58	2017	SRS	14	8.71	0.45
flats58	2017	STR	15	8.77	2.59
flats69	2017	SRS	14	4.51	0.26
flats69	2017	STR	14	4.49	0.24
hdc2237	2017	SRS	20	4.31	0.65
hdc2237	2017	STR	15	4.39	0.73
hdc2259	2017	SRS	11	4.83	0.17
hdc2259	2017	STR	11	4.61	0.15
hdc2320	2017	STR	0	0	0
hdc2344	2017	SRS	20	0.39	0.18
hdc2344	2017	STR	15	0.21	0.17
hdc2346	2017	SRS	0	0	0
hdc2346	2017	STR	0	0	0
hdc2492	2017	SRS	14	0.97	0.17
hdc2492	2017	STR	13	0.84	0.34
hdc2511	2017	SRS	15	3.13	0.4
hdc2511	2017	STR	11	2.67	0.4
nps0064	2017	SRS	11	21.9	1
nps0064	2017	STR	11	22.09	0.98
nps0652	2017	SRS	20	0.47	0.09
nps0652	2017	STR	15	0.57	0.1
nps0671	2017	SRS	10	0.73	0.03
nps0671	2017	STR	11	0.8	0.28
nps1372	2017	STR	0	0	0
nps1373	2017	STR	0	0	0
nps1375	2017	STR	0	0	0
nps1461	2017	SRS	11	9.61	0.9
nps1461	2017	STR	11	9.94	1.26
sjs0099	2017	SRS	14	14.92	0.84
sjs0099	2017	STR	14	14.77	0.99
sjs0138	2017	SRS	17	1.14	0.18
sjs0138	2017	STR	11	1.79	0.65
sjs0318	2017	STR	0	0	0
sjs0330	2017	SRS	12	1.67	0.1
sjs0330	2017	STR	11	2.11	0.56
sjs0417	2017	SRS	11	0.18	0.05
sjs0417	2017	STR	11	0.21	0.13
sjs0427	2017	STR	0	0	0
sjs0454	2017	SRS	12	1.38	0.11
sjs0454	2017	STR	11	1.4	0.2
sjs0473	2017	SRS	15	0.96	0.1
sjs0473	2017	STR	13	1.18	0.43
sjs0526	2017	STR	0	0	0
sjs0682	2017	SRS	18	2.7	0.25
sjs0682	2017	STR	12	2.28	0.29
sjs0983	2017	SRS	11	25.05	2.06
sjs0983	2017	STR	10	24.04	2.34
sjs0987	2017	SRS	12	16.62	0.95
sjs0987	2017	STR	10	16.87	0.83
sjs1004	2017	SRS	11	2.8	0.29
sjs1004	2017	STR	10	2.76	0.31
sjs2605	2017	SRS	14	4.72	0.88
sjs2605	2017	STR	11	6.06	1.23
sjs2620	2017	SRS	20	1.79	0.21
sjs2620	2017	STR	15	1.84	0.26

site_code	*year*	*sample selection*	*transects sampled*	*seagrass area (ha)*	*standard error (ha)*
sjs2622	2017	SRS	11	5.36	0.38
sjs2622	2017	STR	10	5.37	0.36
sjs2688	2017	SRS	10	2.96	0.31
sjs2688	2017	STR	10	3.02	0.25
sjs2781	2017	SRS	18	2.63	0.33
sjs2781	2017	STR	15	2.56	0.42
swh0848	2017	SRS	12	19.3	1.1
swh0848	2017	STR	12	18.05	1.17
swh0883	2017	STR	10	0.01	0.01
swh0901	2017	SRS	18	5.08	0.29
swh0901	2017	STR	13	4.98	0.36
swh0926	2017	SRS	11	6.23	0.29
swh0926	2017	STR	10	6.29	0.32
swh1574	2017	SRS	10	17.1	0.79
swh1574	2017	STR	10	16.91	1.18
swh1626	2017	SRS	13	25.95	2.2
swh1626	2017	STR	12	24.91	2.26
swh1646	2017	SRS	14	3.26	0.26
swh1646	2017	STR	11	3.43	0.73
swh1653	2017	SRS	11	18.78	1.76
swh1653	2017	STR	11	18.8	1.58